AN INTRODUCTION TO PHYSICAL GEOGRAPHY

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WITH NUMEROUS ILLUSTRATIONS AND MAPS

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INTRODUCTION

This book is intended to serve as a general class-book in Physical Geography in schools where geography is taught on modern lines. The requirements of candidates preparing for the Cambridge Senior Local Examination in Physical Geography have been specially kept in view, and the book covers also all that part of the syllabus of the Oxford Senior Local Examination which refers to Physical Geography in the strict sense, as well as the physical part of the syllabus in geography for the London Matriculation, and examinations of similar scope. Among the special features are the large number of diagrams and simple sketch-maps, intended not only to illustrate particular problems, but also to serve as a guide to teachers and scholars in the construction of other similar maps and diagrams. Further, as there is now general agreement that physical geography can only be regarded as coming legitimately under the scope of school geography when the phenomena described are considered in their relation to human life and activities, this aspect of the subject has been carefully kept in view, and references have been given to facilitate further work by teacher and scholar in this direction. Again, as it has always been an objection to the ordinary text-book of physical geography that it treats the subject from too abstract a standpoint, giving, for example, generalised accounts of plains, plateaux, etc., without adequate discussion of particular examples, and thus producing an impression of unreality, this danger has been avoided here by the description of concrete examples, intended to be used by the pupil as models for similar accounts of his own.

Photographic illustrations have been purposely omitted, for many collections of geographical pictures or lantern slides are now available, and these are far more useful than reproductions on the ordinary paper of a text-book can be. For a similar reason detailed large-scale maps, *e. g.* portions of Ordnance Survey maps, have also been omitted. Reproductions of these are never satisfactory, and cannot replace that free use of the actual maps which must be regarded as an essential part of geographical teaching. Many of the diagrams have been drawn by my sister, Miss Florence Newbigin, while I am indebted to Prof. Geikie for the use of Figs. 14, 15, 17 and 18.

I am indebted to the courtesy of Messrs. Fowler and Marriott for permission to use five diagrams from their book *Our Weather* in the present volume.

MARION I. NEWBIGIN.

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CHAPTER I

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The Valley of the Eden and the Pennine Escarpment

Under ordinary circumstances but a small part of the surface of the earth is visible to us from any given point, the view of distant objects being obscured by near ones or by natural features. But any considerable elevation, natural or artificial, which raises us above the level of the adjacent features enables us to see a large part of the surface at once. When such a comprehensive view from hill or church tower is combined with excursions to various points of the area, we can obtain a very good idea of the geographical features of the region selected. We may, therefore, conveniently begin our study of physical geography by describing one or two representative views of this kind.

We shall begin with an English region which shows some interesting features. Let us travel in imagination to the county of Westmoreland, and descend from the railway at the county town of Appleby, or, still better, at the little village of Warcop, which lies a few miles to the south-east of Appleby. As we leave the station we see to the east of us an abrupt line of hills, sometimes descending to the plain

in grassy slopes, and elsewhere ending in a rocky escarpment, the rocks being greyish-white in colour. It is not difficult to find a means whereby the hills can be ascended, and from the crest we have a splendid view of the plain (Fig. 1).

Fig. 1. Sketch-map to show the main features of the topography of the Appleby district. Scale about 10 miles to an inch.

(1) The plain of the Eden, with the river in the centre; this region lies at a level of less than 600 feet above sea-level. (2) Land lying at a level of 600–1,200 feet above sea-level. (3) At a level of 1,200–1,800 feet. (4) At a level of over 1,800 feet.

Let us analyse the elements of the view. At our feet, stretching away to the north-west, lies the plain of the Eden, a broad, fertile valley, well wooded in places, and elsewhere carefully tilled, the ploughed land bearing the

usual English farm crops. From the point at which we stand this low-lying land looks flat; hence we call it a *plain*. We shall find when we walk or cycle over it that it is far from being quite flat, but, relatively to its extension, and to the hill upon which we stand, there are no great elevations of the surface. Through the plain winds the Eden, and from the slopes upon which we stand many small tributaries, permanent in character, flow down to increase its waters. Finally, as the land is level, is fertile, and is watered by perennial streams, we find that the plain is dotted with human habitations, which form groups (hamlets, villages or towns) at specially favourable points.

The distant view to the west we may neglect, and turn instead to our immediate surroundings. From the plain the region on which we stand presented the appearance of a range of hills; it forms, indeed, part of the Pennine Chain. But when we top the summit of the escarpment we find that the mountainous appearance is somewhat deceptive. A mountain is defined as an elevated part of the earth's surface with a relatively small summit area. The region on which we stand, on the other hand, has no very conspicuous summits or peaks, but consists of a great tract of rolling country, of "fells," as they are called, cut into valleys, sharply truncated where it meets the plain of the Eden, but very different from a typical mountain range. Indeed, if we turn our backs upon the escarpment and look eastwards, we might regard the region as a high plain. Such a high plain is called a *plateau*, and when, as in this case, it is cut up by valleys, it is called a *dissected plateau*. This part of the so-called Pennine Range is really only a dissected plateau.

Looking now at details, we find several very marked contrasts with the plain of the Eden below. The fells are not wooded, though we may find patches of trees in deeply cut valleys. They are quite different in their vegetation from the moors of Scotland or Yorkshire, for there is little heather; in most places none at all. The surface is covered with short grass, and because of this abundant grass the lower slopes carry cattle, which do not find sufficient food on heather moors. In contrast with the plain we have no arable land, and in further contrast we have very few dwellings. Even more marked is the relative scarcity of water here, despite a heavy rainfall. We find stream-beds, but in

summer these are often dry, and water does not appear till we get nearly to the bottom of the escarpment. Sometimes at the escarpment we find a series of springs where the water gushes out of the rock, often at a point where a change of slope occurs in the scarps. These springs feed the perennial streams which flow into the Eden below, but the yield of any particular spring varies greatly with the weather, and the few hamlets which are placed on the high ground often have difficulties with their water supply in summer.

A very curious feature is the occurrence of peculiar depressions, or sink-holes, which sometimes occur in a row. These pits are sometimes quite dry at the bottom; in other cases there may be a hole there leading into a narrow passage, where one sometimes sees or hears water running. In other cases, again, there may be an entrance to a cave at the bottom. Elsewhere we have dry stream valleys, only containing water after heavy rain.

To sum up, the upland region in this part of Westmoreland differs from the lowland in the infertility of its soil, which is very shallow, the rock sometimes cropping out at the surface; in the small amount of running water, at any rate in summer time, and in its relief. It is, further, a striking feature that there is a marked break between the lowland and the upland, the latter rising, as we have seen, almost like a wall above the plain.

We cannot now explain the reason for all these peculiarities, nor discuss the many conclusions which can be drawn from this interesting region. One or two points emerge, however, even from the most superficial examination. As we wander over the fells, and observe the rocks which crop out here and there, we soon learn to distinguish two types. One, which often forms a cap on the higher points, is composed of particles like coarse grains of sand; this is called a *grit*, this particular grit being the Millstone Grit, from its use for millstones. The other type is fine-grained, greyish-white in colour, and full of fossils, which stand out on exposed surfaces because they do not weather so rapidly as the rest of the rock. This rock is *limestone*. It allows water to pass through it very readily, the water appearing as springs whenever a junction occurs between the limestone and a type of rock less permeable to water. Water which has percolated through limestone takes up a certain amount of lime, and becomes "hard." Further, owing to

the rapid drainage, vegetable matter soon decays in the shallow soil which overlies limestone. There is, therefore, no great accumulation of what the gardener calls "leaf-mould" and the botanist "humus," this consisting of partially decayed vegetable matter. It is this absence of humus in the soil which prevents heather growing freely, and produces the peculiar pasturages of limestone districts. It also prevents the formation of a rich soil, and makes the district relatively infertile. The absence of humus further makes the streams crystal clear, as contrasted with the brown streams which drain peaty districts; and this, again, causes the streams of limestone districts to be less valuable for the fisherman's purpose than those of non-limestone districts.

Much of the Pennine plateau, then, though not quite all, consists of limestone, with here and there caps of grit.

The plain of the valley of the Eden, on the other hand (Fig. 2), is built up of fine-grained *sandstone* and a peculiar pebble-containing rock locally called *brockram*, and also of soft beds known as *marls*, together with alluvial deposits. When limestone is acted upon by water it dissolves, leaving an insignificant residue to form soil. But when sandstone is similarly acted upon by water, frost, etc., it crumbles to form a fine soil which, when mingled with vegetable débris, is rich and fertile. Similarly, the other rocks of the plain form fertile soil. Part of the difference between plain and upland, therefore, is due to the difference in the kinds of rocks in the two regions.

But this is not the whole story. The rocks which form the Pennine upland are older than those which lie in the valley of the Eden. By a series of earth movements they were folded up into a great arch, and have since been profoundly affected by the long-continued action of wind and weather. The much younger rocks which lie in the Eden valley have been let down by a fracture or fault of the crust, while retaining the horizontal position in which they were originally laid down. From their position, and because of the way in which their component rocks are folded, the uplands have been far more exposed to wear than the lowlands, and the marginal streams, together with the ice of an earlier period, have carried the products of weathering down to the low ground. The loss of the uplands has constantly been the gain of the lowlands, and this has been another factor in promoting the fertility of the plain.

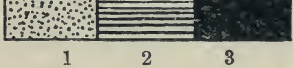

Fig. 2. Sketch-map to show the important features of the geology of the Appleby district, and the effect of the geological structure upon the topography. Scale about 8 miles to an inch.

(1) Carboniferous limestone rocks. (2) Sandstones, marls, conglomerates, etc., belonging to the New Red series (Triassic). These are relatively soft beds, and therefore form lowlands. (3) Ordovician rocks, consisting of slates and volcanic deposits, which being hard form uplands, though not such high lands as the limestone. The amount of millstone grit in the immediate vicinity of Appleby is too small to be shown on this map. A part of the Pennine fault is seen to the east of the vale of the Eden.

This brief description, then, shows us that in this region we have contrasts of relief which bring in their turn a whole series of other contrasts, many of which very directly affect human life. The prime contrast of relief in this particular case is due first to earth movements, and second to the fact that the rocks composing the crust have different characters in the two regions, and have been differently affected by the agents which for a prolonged period have been acting upon them.

The Western End of Lake Geneva

Let us turn next to another tract of country, one far away in space from the preceding. To the south of the town of Geneva, and very readily accessible from it, is a long ridge of limestone rock, called the Salève, rising to a height of over 4,000 feet, and famous for the beauty of the view which can be seen from its summit. Let us ascend this point and consider the different elements of the view, which is far more imposing than the preceding in that all the factors are on a larger scale. Looking northwards, towards the town of Geneva, we see a part of the beautiful lake (see map, Fig. 21, and Fig. 3). The portion of the lake which is visible here lies in the south-western end of that great stretch of relatively flat ground which runs in a north-easterly direction towards Berne, past the lakes of Neuchâtel and Bienne, and is sometimes called the plain of Switzerland. Plain is, however, a very deceptive term to apply, for far from being like the much smaller plain of the Eden which we have just considered, all of which lies below 600 feet above sea-level, this so-called plain stands throughout its extension 1,000–3,000 feet above sea-level. It is thus a plateau rather than a plain, comparable to the plateau of the Pennines rather than to the vale of the Eden.

Across the portion of the plain which intervenes between the Salève and the lake we see the windings of a turbid stream, called the Arve. The origin of this stream we shall consider directly; meantime we may note that its turbidity means that it carries a heavy load of rock waste. It is flowing now over ground with only a moderate slope, whereas in its upper reaches it plunged down steep mountain sides. Rapid though its course still is, therefore, it is slower than it was in the higher reaches, and thus its power of transporting waste is less than it was once. In consequence the water tends to deposit great masses of sand and

silt wherever some cause checks the rapidity of its flow. The banks so formed again act as checks to the movement of the water, which turns aside to avoid the obstacle. The result is that the river has a characteristically winding course, or, as we say, it shows meanders, such meanders

Fig. 3. Sketch-map of the environs of the town of Geneva.
(1) The Salève. (2) The south-western end of Lake Geneva. (3) The Arve meandering over the plain. (4) The Rhone. (5) One of the parallel ranges of hills which form the Jura Mountains. The region which intervenes between the Salève and the Jura is part of the Swiss plain or plateau. The town of Geneva is shown near the junction of the Arve and the Rhone.

being common in rivers in those parts of their course where the slope is slight. The Arve does not enter the Lake of Geneva, but joins its effluent, the mighty Rhone, shortly after it quits the lake—the junction of the clear Rhone and the turbid Arve being one of the sights of the town.

Beyond the Swiss plateau and the town of Geneva we

see a great rampart of mountains, running from south-west to north-east, and cut into peaks by well-marked valleys. This chain of mountains, called the Jura, slopes very steeply towards the Swiss plateau, while the other, or French, slope is much more moderate. Such a dissymmetry is very common in mountain chains, for this is a true mountain chain, not a dissected plateau like the Pennine Range. The precise meaning of this statement we cannot stop to consider meantime, but we may note that the whole range of the Jura is due to a folding of the earth's surface, such folds having been compared to the wrinkles which form on the skin of a drying apple. Such folded mountains are always of recent origin, for their formation makes them unstable, and in the course of time they are destined to be worn down to sea-level. Like the Salève itself, the Jura is built up of limestone rocks, and shows in consequence many peculiarities of drainage.

Having thus identified the lake, the Arve, the Swiss plateau, the rampart of the Jura, let us turn to the south-east. Here the view is very different. Hill after hill arises in an apparently confused mass, and away in the distance we may see the whole chain of Mont Blanc, with its covering of pure white snow and its huge glaciers, or, if the weather be less clear, we may see banks of mist from which only the summits, perhaps only the dome-like summit of the monarch of Europe, emerges, the clouds cutting off all the lower peaks. This great mountain mass is, of course, a portion of the chain of the Alps, and the view from the Salève thus presents us with an epitome of Switzerland. That country, from the point of view of physical geography, consists of three regions: the range of the Jura, built up of limestone and with relatively simple folds; the plateau, made of soft rocks, mostly sandstones and clays, not folded; and the great chain of the Alps, built up partly of limestones, which form the lower hills, and partly of rocks called granite and gneiss, which are very hard and of great age. The Alps are of excessively complicated structure. Not only have the rocks of which they are made been folded, crumpled and contorted in the most complex fashion, but great masses of rock have actually been pushed for many miles over the underlying beds, so that they come to lie far away from the region where they were first laid down.

Without attempting, however, at this stage to explain

their structure, we may just note that this region of the surface has much to tell us which we could not learn from our first area. In some points, it is true, it but confirms the conclusions we arrived at from our study of the Appleby region. There we found that hard rocks tend to occur on hills, soft rocks in valleys. Round Geneva we find that the lowest part of the surface, the plateau, is made up of soft rocks, which lie in more or less horizontal or slightly sloping layers. The Jura and the lower mountains of the Alps are formed of hard limestones, the highest Alps of rocks harder and more resistant than limestones. Again, as a very little observation on the Salève itself will show, the rocks in the mountain regions are complexly folded, and slope, or *dip*, as the geologists say, at high angles.

At the banks of the Arve we may see beds of silt accumulating, and we note that the layers of which these beds are composed are not far removed from the horizontal. They may be laid down on inclined banks, and show corresponding slight slopes, but these are never very great, for if they were the particles of sand and silt would slip down till a position of stability was reached.

In the valley of the Eden we may find sandstones whose layers show similar gentle slopes, as if sand accumulated on a sea or lake shore had hardened into rock. But on the Salève we may see beds or strata of limestone which stand vertically upwards, as well as others which are horizontal. Now it is obvious that no rock laid down in water, as all limestone has been, could have its layers vertical to begin with. We must suppose, then, that after the limestone had been laid down, and had hardened into solid rock, this rock was so folded that the originally horizontal, or nearly horizontal, layers were folded up, as an exercise-book will fold if we exert pressure from the sides. In point of fact, in the Alps far greater complications than this have occurred, but these we need not consider at present.

We saw also in the Appleby region that hard as the limestone seems to be it is readily hollowed out and eaten away by water. We saw from the Salève that the Arve, which rises in the great massif of Mont Blanc, is carrying away, year by year, an enormous mass of rock waste from that mountain group. We may, then, surely draw a few conclusions as to the causation of plains, plateaux, mountains and hills on the earth's surface. It would seem as if we

might say that, other things being equal, soft rocks tend to form less marked features of the earth's surface than hard ones, because they are more readily worn away by water and the other agents which act constantly upon the surface. But we must add that great elevations of the surface, such as the Alps, show by their peculiar construction that they have not been turned into hills merely by the wearing away of the soft rocks around them, but that there has been a folding of the surface, a crumpling which caused them to project above the general level.

The Monti Albani near Rome

Let us take one other region, which exemplifies some features we have not yet observed. This is the district round the Lake of Nemi near Rome, in the famous Alban Hills. To reach the region we leave Rome by train, and journey southwards across the Campagna, noticing as we travel the straight lines of the ancient aqueducts which cross the marshy plain. Presently the line begins to ascend, and we mount the slopes of vine- and olive-covered hills. Descending from the train, we can wander over the wooded slopes, and note from many points of view our very curious surroundings. Any good view-point shows us a feature absent from the two previous surveys—for from any such point we can see the broad waters of the Mediterranean. Between us and that sea stretches a broad band of pasture-land, the Campagna, marshy and unhealthy still, if no longer the haunt of fever it was once. This is chiefly given up to cattle, the vineyards extending but a short distance out from Rome, or from the Alban Hills upon which we stand.

A point sufficiently elevated to enable us to see over the hills themselves, or one on their eastern slope, will show us another surface feature—the Sabine Hills. These, which are themselves but a part of the Apennines, the great backbone of Italy, stretch in a general north-west to south-east direction, and are separated from the Alban Hills upon which we stand by a broad valley. Very remarkable is the way the Alban Hills rise abruptly out of the plain. But the most striking feature is still to be seen. This is the presence of rounded lakes, that of Nemi being the most beautiful (Fig. 4).

Lake Nemi lies in the centre of the hills, and is a small

lake not more than about three and a half miles in circumference. As contrasted with Lake Geneva it is extraordinarily regular in shape, and as contrasted with that and

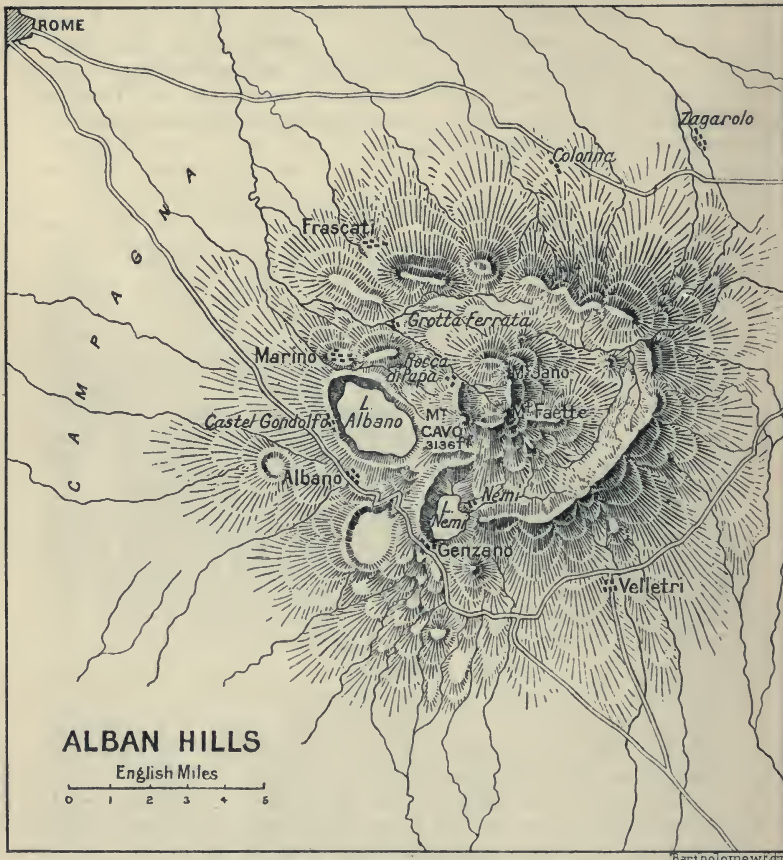

Fig. 4. The Alban Hills and their Lakes.

with our British lakes it has no important inlet and no natural outlet. From its margin the beautifully wooded banks rise steeply to form a perfect rim round the edge of the lake basin.

Two other basins of similar shape occur in the hills; one contains Lake Albano, which is only less beautiful than that of Nemi, while the third basin is dry. Both the lakes seem to be fed by subterranean springs, and both have their overflow carried off by artificial outlets, hewn through the rocks of the containing walls. As contrasted with the marshy, infertile and treeless Campagna, the Alban Hills are fertile, well wooded, and produce abundant olives, vines and fruit-trees.

The combination of all these characters, and more especially the peculiarly regular form of the lake basins, would induce even an inexperienced observer to conclude that some exceptional force has been at work here. The plain of the Campagna, the hills and valleys of the Apennines—these can easily be paralleled elsewhere, but the occurrence of hills of regular shape, rising abruptly from the plain, containing rounded lake basins, these can only be due to one agent. Obviously the Alban Hills are old volcanoes, and the lakes are depressions such as often occur in the vicinity of volcanic vents, and are caused, apparently, by the collapse or subsidence of a part of the crust owing to the removal of the underlying material in the course of volcanic eruptions.

Obviously, then, the hills themselves are due to the throwing out of material by the volcano which once occurred in this region. A glance at the map of Italy will show that in addition to the Alban Hills to the south-east of Rome, there occurs to the north-west a row of volcanoes, each carrying one large lake, in place of the separate basins of the Monti Albani. These volcanoes no longer form conspicuous hills, and have no special names; but the lakes are called in order from the north to the south Lakes Bolsena, Vico and Bracciano. Further, we find that the Campagna itself is floored with a material which was certainly once poured out from a volcano, and receives the name of volcanic ashes or tuff. Similar material forms small elevations of the surface, notably the famous seven hills on which Rome is placed.

According to Prof. de Lapparent, some of these volcanoes were still active so short a time ago as the early centuries of Roman history, so that, compared with the forces which produced the Pennine fault, or even those which raised the Alps into folds, we are dealing here with agents but of

yesterday. Taking up, then, a position on the highest point of the Monti Albani, where we can see at once the Campagna with the sea bounding it to the west and the slopes of the Apennines, we may say to ourselves—this plain is but little above sea-level, despite its extensive covering of volcanic ashes. Therefore, if we think of those early days before the volcanoes were active, the plain was probably below sea-level, and we had a folded mountain chain, comparable to the Alps, though on a smaller scale, which faced a gently sloping shore, covered by shallow water. When the volcanoes became active they not only covered that shallow sea floor with tuff, and so raised it above sea-level, they not only raised up close to their vents the present Alban Hills, but they also poured out a great mass of material which was afterwards cut up by the action of streams and other agents to form the numerous small hills which rise from the Campagna, and thus they made Rome possible.

The result, then, of our brief study of three selected regions has been to show not only that the surface of the earth presents great variation in relief—plain, plateau, hill and mountain alternating with one another, but also that the causation of this varied relief is manifold. In the Appleby region we found that simple forms of earth movement, combined with the existence of differences in composition of parts of the earth's crust, resulted ultimately in the production of marked relief, because of the varying effects of the modelling tools always at work on the surface.

The Alps showed us that those stupendous mountain chains which rise up at parts of the earth's surface are not due merely to the action of the denuding agents, as is the relief of the Pennines, but must be ascribed to folding of the surface, to the formation of mighty wrinkles.

Finally, the region round Rome made clear to us that volcanoes are, within certain limits, potent agents which can produce marked features of surface relief during periods which are geologically very short.

The North Sea

So far we have discussed only examples of land surfaces, but before we can profitably take a general survey of the globe we must consider also the sea bottom. In this case

direct observation is impossible. From no standpoint can we survey directly the abysses of the Atlantic and Pacific or the shallows of the smaller seas. But man has, nevertheless, succeeded in surveying many of the oceans; his sounding instruments, like enormously elongated fingers, have penetrated the great depths; his dredges, thermometers, photographic plates, and so forth, have all yielded details which have helped to complete the picture, and we can now give a fairly accurate account of the sea bottom over a considerable part of the surface of the globe.

Let us begin by a brief discussion of the North Sea, supposing ourselves capable of travelling along its floor from one coast to the opposite one. The accompanying section (Fig. 5) is drawn along a line from Newcastle to the mouth of the Elbe, and shows us, despite the great exaggeration of the vertical scale, that the sea floor in this region is not

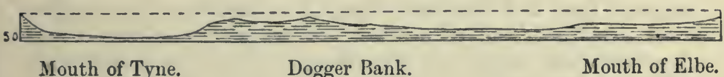

Fig. 5. Section across the North Sea from Newcastle-on-Tyne to the mouth of the Elbe. The section shows the relatively deep water (maximum 45 fathoms) which intervenes between the Dogger Bank and the eastern coast of England. The vertical scale is exaggerated about 250 times.

more than an undulating plain. If we took soundings continuously throughout the journey of 480 miles which separates Newcastle from Hamburg, we should nowhere find depths greater than 45 fathoms—*i. e.* 270 feet. In the middle of the Dogger Bank we should find water shallower than 10 fathoms—that is, 60 feet. Thus, once we had left the shore, we should find that the undulations of the surface did not greatly exceed 200 feet, and such a region, if raised above sea-level, we should certainly describe as a plain.

One other point is important. If during our course we collected specimens of the material forming the bottom of the sea, we should find that throughout this consisted of land-derived material. The exact nature of the deposit would be found to vary considerably. Here we should find sand, here clay; in one place gravel and in another fine mud, but everywhere we should be able to recognise land waste.

There is something more than this. As we travel over the Dogger Bank we shall find that the dredge brings up, not sea animals only, but fragments of bones and teeth of land mammals in abundance. From this bank have been collected in the trawl bones and teeth of such mammals as the woolly rhinoceros, the mammoth, the reindeer, the Irish elk, the hyæna, the stag, the beaver, and so forth, almost all animals which have long since ceased to occupy Britain. We note also that while the Dogger Bank comes up within less than sixty feet of the surface, it is separated from the north coast of England by a relatively deep channel. The presence of these bones and teeth shows that it must once have been part of a land surface. When it was land, the southern part of the North Sea, which is also shallow, must also have been land, and England would thus be united to the continent. The rivers of the continent must then have been prolonged over this land surface, and it is believed that the relatively deep area between the Dogger Bank and the coast of northern England marks the course of an old river valley, of an enlarged Rhine, to which what are now the rivers of northern England must have been tributary.

Our journey across the North Sea, then, has shown us that this particular part of the sea floor exhibits many of the features of a land surface. It is a region of gentle undulations, like that which forms the plain of England and of continental Europe. As the rivers descending from the mountains spread their load of waste over the plains, so, assisted by the waves, do they spread the remainder of their load over the sea floor. That over the Dogger Bank there occur the sub-fossil remains of animals which lived in Britain in a not very remote period, suggests that land and sea—at least shallow sea—must alternate in position. Finally, we should note that at both ends of our line of section the land slopes down gradually to the sea bottom, and at neither side does the land adjacent to the shore rise to any great height.

To this section through the shallow part of the North Sea another has been added (Fig. 6), taken from Buchan Ness, off the coast of Aberdeenshire, to The Naze in southern Norway. This section is drawn to the same scale, and shows that here the depths are considerably greater. Soon after leaving the coast-line the section passes through a

depression, the Buchan "Deep," where the sea floor sinks to a level exceeding sixty fathoms. The bottom then rises again, the section just touching the edge of the famous fishing-bank called the Long Forties. The water here is comparatively deep—over forty fathoms—but the bottom consists of shingle mingled with broken shells of periwinkles and dog-whelks, which only live between tide-marks. The existence of these broken shells is believed to show that the edge of this bank was once the shore-line of Scotland, and they thus confirm the conclusion arrived at from the bones of the Dogger Bank, that there has been recent subsidence in the region of the North Sea.

Following the section across the middle of the North Sea, we see nothing worthy of special note till the Norwegian coast is approached. Till this is done we have an undulating

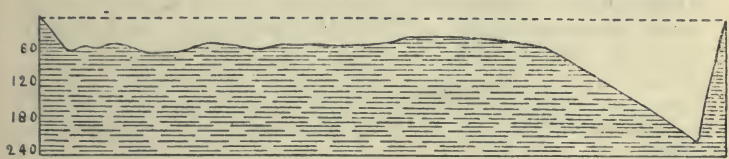

Fig. 6. Section across the North Sea from Buchan Ness to The Naze. The water in this part of the North Sea is deeper than further south. Note the remarkable "gully" close to the coast of Norway. The vertical scale is exaggerated about 250 times. The depths are in fathoms.

surface, covered with water varying in depth from thirty to sixty fathoms. But as we approach the coast the sea floor sinks suddenly into what is known as the Norwegian Gully, a narrow channel which fringes the east coast of Norway, and is like an arm of the deep Atlantic pushed into a shallower sea. The deepest point in this hollow which is crossed by the section-line is less than 230 fathoms, but further to the east, in the Skager Rak, a maximum depth of 480 fathoms (or 2,880 feet) is reached. This Norwegian Gully is a very remarkable feature, and the point which it is necessary to emphasise here is that with the sinking of the sea floor we have associated a great elevation of the land surface. From the deep fiords of Norway the mountains rise abruptly and to a great height. It is very usual to find that when high mountains fringe a coast-line, then the sea which washes them is deep.

If dredging is carried out along this section-line it will

be found that, as in the previous case, the sea floor is entirely covered with land-derived material.

The Atlantic

Let us add to this account of the North Sea a few notes on the differences which would be presented by one of the great oceans—*e. g.* the Atlantic. Suppose we started out on a voyage of oceanographical exploration from, *e. g.* the west coast of Ireland, the first thing we should find would be that for a certain distance out from the shore, the exact distance varying greatly at different points on the coast, the slope of the sea bottom is gentle. Here, as in the North Sea, we have the waste of the land spread out. But soon after we have crossed the 100 fathom, or 600 feet, line, the slope steepens rapidly. We require a longer and longer

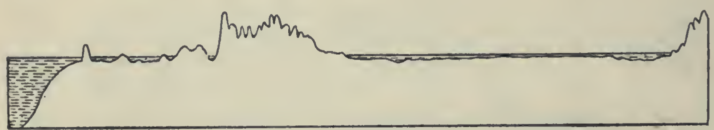

Fig. 7. Section from Norway across the North Sea and through Scotland to show the Continental Shelf and Slope.

Beginning at the right note the Norwegian Gully, the shallow North Sea (note position of the Buchan "Deep"), the Highlands of Scotland, the depression of the Great Glen, the position of St. Kilda on the margin of the Continental Shelf, and the steep slope downwards to the depths of the Atlantic. The horizontal and vertical scales are the same.

sounding-line, for, from depths of under 100 fathoms, the bottom sinks rapidly to those of 1,000 to 2,000 fathoms, and in places in the Atlantic it sinks to a depth of over 27,000 feet. The differences between the conditions which obtain in this region and those in shallow seas like the North Sea may perhaps be realised when we note that what we called the Buchan "Deep" (Fig. 7) in the North Sea does not exceed 366 feet in depth; but the deepest part of the Atlantic is the Blake Deep, which lies north of the island of Porto Rico, and sinks to 27,366 feet.

Again, in the North Sea the Dogger Bank comes in places to within fifty feet of the surface, but the so-called ridge

which divides the deep basin of the Atlantic into two parts never rises nearer the surface than 1,500 feet, and is sometimes 12,000 feet below the surface. This ridge, the Dolphin Ridge, runs down the Atlantic lengthwise, so far as lat. 40° S., and rises to the surface in the islands of the Azores.

Again, we have repeatedly emphasised the fact that the North Sea, and the Continental Shelf, as we call the region covered with water of less than one hundred fathoms depth which stretches out from the land masses, are both alike covered by land-derived débris. But no such waste finds its way into the great depths of the Atlantic. Here the sea-floor, except in the deepest regions, is covered by a whitish deposit, containing the shells of a little organism called Globigerina, and therefore named Globigerina ooze. This has been formed by the slow accumulation of the shells of these tiny organisms, which live in the upper layers of the sea water, and sink downwards as they die. In some of the deeper regions the Globigerina ooze is replaced by another deposit, called Red Clay, whose origin we shall have to consider later. It also is formed within the sea, and is not derived from land except to the small extent that it contains particles of volcanic dust, carried out to sea by winds.

General Characters of the Ocean Floor

We may say, then, that shallow seas, and those marginal portions of the ocean floor which we call continental shelves, partake of many of the characters of land surfaces. Like land surfaces, they are covered by the waste carried down by rivers, and they possess another character in common with land surfaces in that river valleys are often prolonged over them. We saw in the case of the North Sea that there is reason to believe that the slight depression of its surface which lies near the coast of northern England is the remains of the valley in which the magnified Rhine flowed, at a time when the level of the land stood higher than at present. In some other regions this condition is even more marked. Thus we find that the valley of the river Hudson, in the United States of North America, is prolonged for many miles out along the Continental Shelf, beneath the level of the sea, and the same thing is true, though to a

less marked extent, of the Delaware, the St. Lawrence and some other rivers. Obviously, then, the Continental Shelf is in all essentials a part of the surface of the land, slight changes of level bringing it above or below the level of the sea from one period to another. Where, as on the east coast of England, a wide plain fringes the shore-line, it is quite obvious that the sea floor is merely a continuation of the coastal plain.

The distinction between the floor of the oceans and the land is much more marked, and shows many signs of being much more permanent in character, though the oceans have not been, as geologists were once disposed to believe, constant throughout geological time. The ocean floor displays one marked peculiarity as contrasted with land surfaces or continental shelves, and that is the complete absence of minor irregularities of surface. The land, as we have suggested, is constantly being acted upon by frost and heat, by wind and especially by running water, and in places by flowing ice. Such agents modify it continually and cut up its surface into a multitude of minor features of relief. Continental shelves and the floor of shallow seas may show remnants of these irregularities, smoothed down by the action of the waves, but these do not occur on the floor of the great oceans. Here the surface is far from uniform, but it rises and falls in great swells, and has not the accentuated relief of a land surface. Another important characteristic can be gathered from the figures just given. This is that while the ocean floor does not show the minor features of relief seen on land surfaces, yet the gross features are accentuated in it. The greatest depth in the ocean, which, so far as is at present known, is in the Nero Deep in the North Pacific (31,614 feet), is greater than the greatest height of the land, and the mean depth of the ocean (about two and a half miles) is greater than the mean height of the land (about half a mile).

Summary

We have now looked at the general characters of three small land areas, and two marine areas. These typical regions have furnished us with a sufficient basis of facts to draw one or two general conclusions.

We see, in the first place, that we can distinguish three

elements on the surface of the earth. There is first the *lithosphere*, that solid crust which forms the land and also the floor of the oceans, and envelops the centrosphere, the region removed from our direct observation.

But the lithosphere shows a marked distinction into two parts, the one being the continental platforms (areas somewhat larger than the continents which stand upon them), and the oceanic basins (deeply depressed areas in which water accumulates). The great masses of water in these basins constitute the second element, or *hydrosphere*, and we have seen that the water of the hydrosphere is not confined to the ocean basins, but spreads over those margins of the continental platform which we have called the continental shelves.

Finally, round the continents and oceans alike we have an enveloping zone of air which forms the atmosphere. Now, the general subject of geography is the earth in the widest sense, and physical geography may be defined as the branch of geography which deals with the characters and interrelations of land, water and air. It is the fact of these interrelations which make life possible on the surface, and only at their zone of contact does life occur. It is a great part of the interest of physical geography that it studies the physical phenomena manifest at the surface from the point of view of their influence upon the phenomena of life, especially of human life.

It is customary to include also in physical geography some consideration of the form and dimensions of the earth, and of methods of representing portions of its surface and of finding the position of places upon it. Strictly speaking, these subjects belong to mathematical geography, but there are certain conveniences in including them under the heading of physical geography.

The subject matter of this book therefore falls under four headings. We have first to consider the lithosphere or crust of the earth, its relief, its materials, and the way in which it is being modified by the various forces at work upon it. Then the elements of mathematical geography must be considered. We must next study the atmosphere, including climate and weather. Thirdly, we shall discuss the characters of the oceans, their deposits, the movements of their waters, and so forth; and, finally, indicate the general bearing of the conditions described upon human life.

SECTION II—THE FORM AND STRUCTURE OF THE LANDS

CHAPTER II

LAND FORMS AND METHODS OF REPRESENTING RELIEF

Distribution of Land and Water.—Classification of Relief Features.—Methods of Representing Relief.—Map-reading.—Examples of topographical Maps.

Distribution of Land and Water

In the previous chapter we saw that a large part of the surface of the globe is considerably depressed below the level of the remainder, the depressed regions forming the ocean basins. Above these depressed areas rise the continental platforms, but, as we have seen, the platform in each case is somewhat larger that the continent which it carries, for the sea has invaded its margin—the Continental Shelf. The result is that the oceans cover a greater extent of the surface than the basins in which they lie. No less than seven-tenths of the whole surface of the globe is covered by water, leaving three-tenths for the land. That there is even this proportion of dry land, however, is the result only of the depth to which the basins sink, for it has been calculated that if the surface of the land was planed off smooth and the material so obtained thrown into the sea till the whole was at one level, we should have a uniform surface covered with about a mile and a half of sea water.

The average height of the land, indeed, is only about half a mile above sea-level, and the average depth of the sea is about two and a half miles below sea-level. The prime fact of the relief of the globe, then, is that the formation of deep hollows has drained the water off about three-tenths of the surface, and permitted the dry land to appear.

The ocean basins, though we give them different names, are continuous over the surface, but the land surfaces are

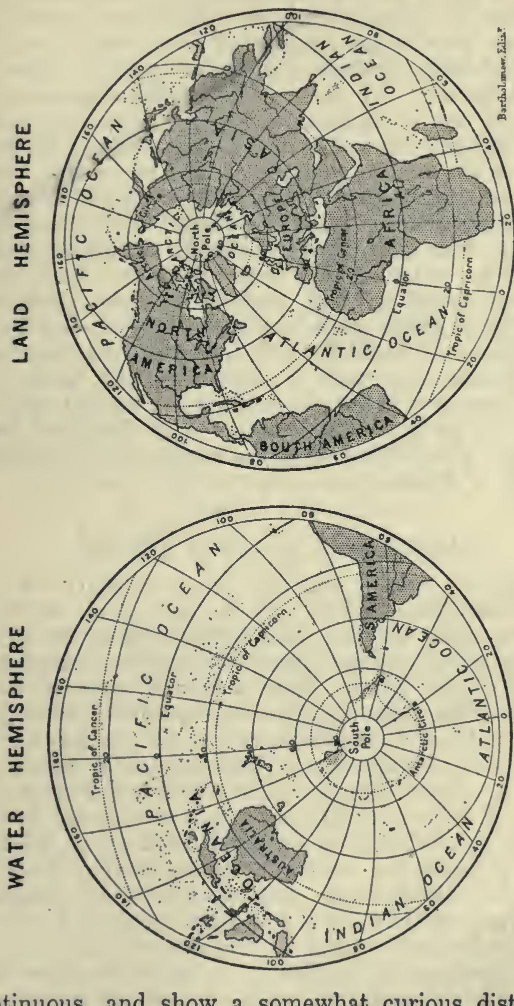

Fig. 8. The Land Hemisphere and the Water Hemisphere.

discontinuous, and show a somewhat curious distribution. As a globe will show, they are concentrated in the northern,

or land, hemisphere, and show their maximum development not far from the Arctic Circle. Similarly, the oceans are concentrated in the southern, or water, hemisphere (Fig. 8). This irregularity of distribution is still more marked, as the German geographer Penck has shown, if we take Berlin as the central point of the northern hemisphere. Then we have a very clear division into a northern land hemisphere, and a southern water one. The map showing the hemispheres thus arranged brings out an interesting point as to the relative position of land and water. It will be seen that, as a general rule, the antipodes of a continent is an oceanic surface. Thus the whole block of land formed by Europe, Asia and Africa is balanced at the other side of the globe by water, except that Spain and New Zealand correspond to one another, and the southern extremity of South America corresponds to a region in south-eastern Asia. The continent of Australia corresponds to the basin of the North Atlantic, the Antarctic continent to the Arctic basin.

The causation of these peculiarities is a subject into which we need not go here, but it seems clear that they are due to the cooling and shrinking of the earth, and the consequent formation of depressions on its surface.

Classification of Relief Features

Having thus briefly discussed the prime feature of the earth's relief, the division into sea and land, we have to consider next the detailed relief of the land surface.

There is as yet no great unanimity as to the best classification of the land forms. From a human point of view the actual elevation above sea-level is important, for it greatly affects climate, and, therefore, crops and population. Thus one suggested classification is into Lowlands, Uplands and Highlands. In this case the Lowlands are defined as the land which lies below 660 feet, or 200 metres, above sea-level; the Uplands extend from this limit up to 2,000 feet, while Highlands are regions lying above that level. But though this classification has a certain convenience in descriptive geography, it has the great objection of telling us nothing about the actual form of the surface. According to it the Swiss plain or plateau of which we have already spoken ranks as an upland, yet in relation to the surrounding mountains it shows all the characters of a lowland. Such

a classification as the following, which takes account of form, seems therefore more useful. We distinguish first between positive and negative land forms, dividing the former into plains, plateaux and mountains, and the latter into valleys and basins. But before we can say anything of these in detail, we must begin by considering briefly methods of representing relief.

Topographical Maps

It is necessary, however, to point out first that no explanation of the principles underlying topographical maps can suffice to make the use of these perfectly clear. A topographical map is a method of representing on a flat surface, by means of various conventions, the complex relief of a given area. Its value is estimated in terms of the picture of the surface which a trained observer, unacquainted with the particular area, can form of the region depicted. His capacity to form such a picture is called map-reading, and involves two factors: first, and most important, a general acquaintance with the types of relief which occur on the earth's surface, and this can only be acquired in the field; and, second, a knowledge of the symbols or conventions employed in the construction of the map.

Surface relief, from the purely human point of view, may be said to be important for two reasons. In the first place, the degree of slope, other things being equal, greatly affects man's power of rapid movement, and his power of transporting burdens, whether directly or through the agency of domesticated animals or machines. Second, the relief is the factor which determines the direction of flow of water, a point often of great human importance. If, then, we are confronted with a topographical map of a small area we want to be able to determine at once which way the streams flow, and the general nature of the slopes. In order to understand how these facts are represented on the map, some practical observations should be undertaken.

Great Britain and Ireland are areas remarkable for the great variety of rocks composing them, and for the resultant great variety of relief. In addition to possessing some areas with a very considerable mean elevation above sea-level, they contain also many regions of moderate relief, often devoted to pasture or other uses which exclude intensive

cultivation. The student should select the area within easy reach which has the best marked relief, and purchase an Ordnance Survey map of it on the scale of one inch to the mile. He should then study the map as carefully as he can, and mark upon it with a pencil what seems to him a feasible route up some moderate elevation. Then he should visit the area, and endeavour to ascend the hill selected by the marked route. It is quite possible that this will be found difficult or impossible, because some trifling fact indicated upon the map was not noticed when the route was planned. A series of excursions of this kind, systematically carried through, will give more real insight into the construction and use of topographical maps than much reading. If a few days can be devoted to the area, as in holiday time, it is a good plan for a different leader to be chosen for each day. The leader whose plan of campaign includes the scaling of high cliffs, the crossing of wide streams, of a series of valleys, or of regions where the flow of water is uncertain, will in all probability have the need for careful map-reading borne in upon him much more thoroughly than if he had to suffer alone from his carelessness or inexperience.

Those students are, of course, fortunate whose region includes uncultivated tracts of considerable elevation where free roaming is possible, but, as suggested, there are not many parts of Great Britain where an area of well-marked relief is not somewhere within reach, and holiday time always gives some scope for such practical work. Another useful exercise is to attempt to give reasons for the winding course of a given road—few roads being quite straight except for short distances.

When by such exercises a general notion of the problem to be faced has been obtained, it is possible to proceed with profit to a consideration of the principles of map-making. It will be obvious that there are two main methods of representing relief, these being sometimes used in combination. The two methods are by the use of hachures, or hill-shading, and by contour lines. On small-scale maps the former only is possible, and when well done it should show up the form of the country at a glance. In hachuring the map is shaded dark for steep, and light for gentle, slopes, the lines being usually drawn in the direction of the slopes, *i. e.* in the direction in which water would run. Where the slopes are steep the lines are drawn very near together, producing the

dark effect just noticed. Similarly on slight slopes the lines are more widely separated, giving a light effect, while a practical absence of slope is shown by the absence of shading. On small-scale maps only the greater elevations can be shown, but a large-scale map with hill-shading, if well drawn, gives a very vivid representation of the form of the land.

But though it may thus give a very good general representation of the country, a hill-shaded map can never be very accurate. We cannot calculate from it the actual slope in any particular case, nor can we aid our visualising faculty by drawing sections across the country. On this account contour lines, which give a great deal more detail, are very commonly employed in large-scale maps, though to these hill-shading is sometimes added, as in the Ordnance Survey maps. In other cases visualisation is aided by washes of colour, a special tint being employed for areas lying within certain limits of height.

The principle of contouring is exceedingly simple. On a given area a line is drawn through all points lying at the same elevation above sea-level, and this is a contour line. Another series of points is then selected lying 10, 20 or 100 feet above the first, and these are similarly connected, and so forth. The difference in height between the points lying on one contour line and the next is called the contour interval, and the contour interval, if not given at the side of the map, may be learnt by noting the different figures on the successive contour lines. Thus, if one line is marked 100 feet, and the next 200 feet, the contour interval is obviously 100 feet. In a country of high relief, where the contour lines are numerous, it is customary to distinguish in some way every fifth or tenth contour line, in order to facilitate map-reading. Thus, every fifth or tenth line may be of a different colour, or may be dotted instead of continuous. In this case the numbering is for clearness usually limited to these special lines. Thus in the very beautiful Swiss topographic map the contour interval is 30 metres, or nearly 100 feet, but the numbers appear only on every tenth line, which is dotted. The vertical interval between one dotted line and the next is thus 300 metres.

In addition to the contour lines it is usual to show the actual heights of certain selected points on topographical maps. Thus if on a map we see the contour line of 2,000

feet forming a ring, and within it the figure 2,018, we know that the summit of a peak is occupied by an area every point in which is over 2,000 feet in height, while the highest point does not rise above the height named. Similarly the lowest point of a depression or valley may be shown.

As the vertical interval between one contour line and the next is fixed for every map, it is obvious that the nearer the contours are together the steeper must be the slope, while the further apart they are the gentler it is.

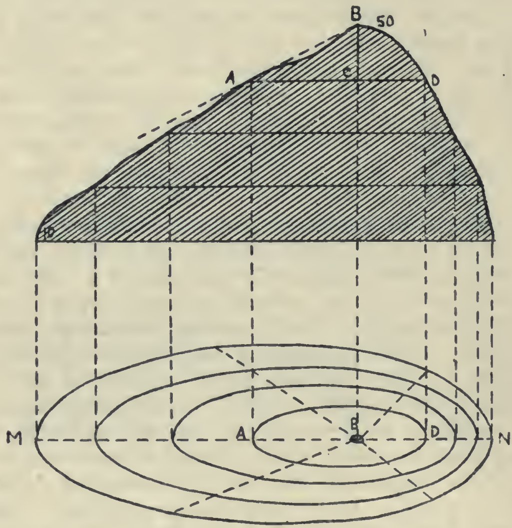

Fig. 9. Diagram showing how contoured maps are constructed.

The accompanying diagram (Fig. 9) may help to make this point clear. The upper figure represents a hillock fifty feet high of which it is desired to make a topographical map. The surveyor places a pole at the point B, on the summit of the hill, and another at A, a point at a measured distance down the slope at one side. By means of a clinometer the angle of the slope at A is ascertained. If BC be a vertical line drawn through the summit of the hill, then it is obvious that on our map the point B, which marks the summit level, must lie within the contour line running through the

points A and D, the exact distance within the line being indicated by the intersection of the vertical line with the horizontal line AD. Now, in the right-angled triangle ABC we can measure the angle at A, and we can measure also the distance AB, therefore all parts of the triangle are known, and we can determine the distances AC and CB. If we arrange the triangle so that BC measures ten feet, then AC and CD represent the distances from the point B through which the contour line must be drawn. The same process can be repeated down the slope of the hill, and also at different sides of it. A contour diagram, such as that shown, can then be drawn, and it will be seen that necessarily the contour lines lie nearer together the steeper the slope. The diagrams illustrate another point, which is, that the contoured map does not represent distances with perfect accuracy, especially on steep slopes. Thus on the map the actual distance between A and B is *represented* by the shorter distance AC. By using either a trigonometrical method or a geometrical one it is easy to calculate the amount of error in any particular case, *i. e.* to correct for slope, and it is worth while doing this in the case of a few considerable mountains. In actual practice it will be found that the error is insignificant, compared with the constant deviations from the direct line which are always necessary in mountain climbing.

It is further obvious that, as the map has been based upon a survey of all the slopes of the hill, a section can be drawn through any part of it, and the hill be thus reconstructed from the facts represented on the map. This should be done on ruled or squared paper. For example, if a section be drawn along the line MN in the lower diagram, the form of the hillock shown in the upper diagram will be reproduced.

A good many other features of contoured maps can only be learnt by constant use, but one or two further hints may be given. If a contoured map be carefully examined it will be seen that the lines often show curious bends, sometimes turning upon themselves at an acute angle. On the accompanying sketch (Fig. 10) it will be seen that such acute bends occur in a series of contour lines, and that the bend is *towards the next higher contour* in each case. Even if no streams were marked we should know at once that these bends meant that valleys were running up the hill. It is usual for streams of any size to be indicated by such bends in the contour

lines, or, in other words, most streams eat back valleys into the hills down which they flow. In the same sketch, however, we notice that certain contours bend *towards the next*

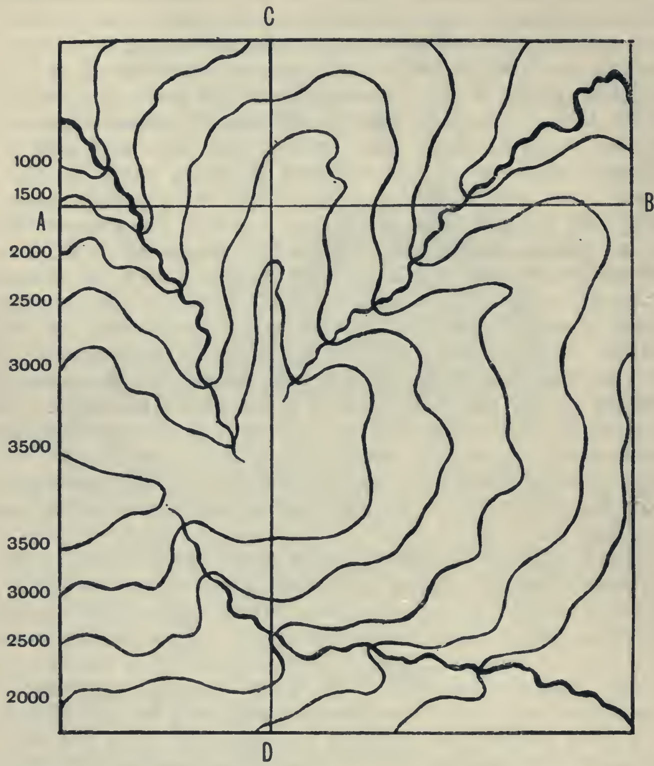

Fig. 10. Fragment of a contoured map, showing three streams arising in a hilly region. Note the bend of the contour lines up the valleys of the streams. Scale two miles to the inch. Contour interval 500 feet.

lower line. This obviously means that a spur is running out from the main hill, such a spur being clearly seen in the upper part of the diagram, and shown in the section along the line AB.

Again, as the diagram suggests, the contour nearest a

stream, on either bank, is part of the same line, which simply means, of course, that streams run in valleys.

A topographical map, in addition to showing relief, shows also watercourses, glaciers, lakes and other bodies of water, where these exist. Frequently, also, it indicates vegetation, as presence or absence of wood, of cultivated land, of bog, etc. In addition, symbols are used to indicate the facts of human occupation, *e. g.* roads, railways, dwellings, etc. There is a general resemblance in the symbols used by different countries for these various purposes, but all topo-

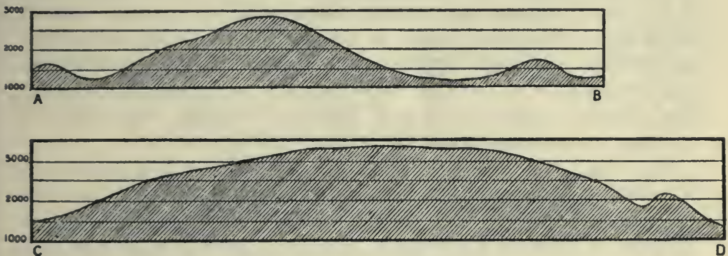

Fig. 11. Diagrams to illustrate the method of section-drawing.
The upper section is drawn along the line AB in Fig. 10, and the lower along the line CD. The first shows the mountain spur which runs out from the central hill, and is bounded by two lateral valleys, and the second shows part of the central mountain region. The lines in the sections correspond to the contour lines of the map. Horizontal scale about 2½ times the vertical.

graphical maps give in some form or other an index to the symbols employed. These symbols should be carefully learnt in the case of the British Ordnance Survey map. Other topographical maps which are well worth study are the Swiss map, very interesting because of the well-marked relief and the presence of glaciers, no longer present in our own country, and the maps of the U.S.A. Geological Survey, which show a number of interesting phenomena which are scarcely represented in our own area. The French 1:100,000 map (*Ministre de l'Intérieur*) is a very good example of a map with hill-shading, and shows both the advantages and the disadvantages of this method. The sheets relating to the Pyrenees will be found especially interesting.

A comparison of the French hill-shaded map with the sheets of the Swiss one will show a rather interesting point in regard to contoured maps. We have said that they are more accurate but less immediately expressive than hill-shaded maps. But it should be noticed that accurate though they are in the facts they represent, a rigorous selection has to be made in regard to those represented. In the Swiss sheets the contour interval is thirty metres. Therefore no terrace or elevation of less height finds a place on the map, even though it forms a marked natural feature. Thus cones laid down by tributary streams on valley floors are not shown unless their height reaches thirty metres, and so with other features. Yet in regions of low elevation such heights may become important. The difficulty is sometimes got over, as, *e. g.*, in the American survey maps, by varying the contour interval in the different sheets, but this, of course, makes the maps not strictly comparable.

On the Ordnance Survey maps all heights are calculated from supposed mean sea-level at Liverpool, this being called Ordnance Datum. The method employed is usually that of triangulation from a carefully measured base-line, the heights and positions of prominent points being obtained by a theodolite. In the case of the English Survey the base-line is on Salisbury Plain, and from either end of it the angle made by the tops of hills, etc., with the horizon is measured, heights and distances being then obtained by trigonometry. The apices of the triangles selected are indicated by Bench Marks, consisting of a broad arrow with a horizontal line through the point, such Bench Marks being often seen in country rambles. By a continuation of the process a chain of triangles is formed over the region to be surveyed.

Heights can also be measured by means of an aneroid (see Chap. XIV), a fall of pressure of one-tenth of an inch indicating a rise of about 90 ft. in the case of small elevations. Another method, often employed by explorers, is the hypsometric method, depending on the fact that the boiling-point of water diminishes with altitude. Further details in regard to the making of topographic maps will be found in the books mentioned at the end of this section.

CHAPTER III

THE GENERAL CHARACTERS OF THE RELIEF FEATURES

Positive Surface Features.—I. Plains, Coastal and Interior, their Origin by Denudation and Deposition.—II. Plateaux, their differences from Plains.—III. Mountains and Hills: (1) Folded Mountains and the Alpine System; (2) Dislocation Mountains; (3) Relict Mountains; (4) Accumulation Mountains; (5) Laccoliths.—Negative Surface Features.—I. Basins.—Importance of basins of Internal drainage.—II. Valleys.—The African Rift Valley.—Bearing of Rift Valleys on the question of the Origin of Ocean Basins.

Positive Surface Features

We have already noted that Positive Relief Features may be divided into Plains, Plateaux and Mountains. Plains may be subdivided into Coastal and Interior plains, according as they fringe the sea, or lie far from it.

I. Plains.—*Coastal plains* are of all widths. In the estuary of the Clyde we find that the sea is fringed by a piece of flat ground, often only a few yards wide, and but slightly raised above tide-marks, which is bounded on the inner side by a cliff of considerable elevation. The numerous health-resorts of the region are built in districts where this *Raised Beach* is specially wide, and it will be generally found that while the older houses are actually on the plain, the newer tend to be placed upon the bank behind, and can therefore only be reached by a steep road. This is a very simple form of coastal plain, and one whose origin is obvious. The cliff was clearly once the margin of the sea. Against it the waves beat, armed with a load of waste brought by the streamlets, or wrenched from the rocks of the shore. The cliff was thus gradually eaten back, a beach being formed in front of it. Later, a slight earth movement took place, and the beach was raised to form the existing narrow plain. Such a plain is said to be formed by *marine denudation*, that is by the wearing back of the shore by the waves, and its mode of origin is shown in Fig. 34, p. 97.

Another type is suggested in many other parts of our coasts. Many rivers, as we know, tend to silt up their

Fig. 12. Portion of the Coastal Plain on the west coast of Dutch New Guinea.

The nearer river is the Kamura, which bifurcates near its mouth; the two others are the Mimika and the Kaparé, which unite. The hills are the foot-hills of the Nassau Range, the position of the huge precipice which bounds the central portion of the range being shown at the top of the figure. The coastal plain, which is remarkably level, is constantly flooded by the rivers and is swampy, despite the enormous load of waste which they bring down. No rock is visible over its surface, and it is thus obviously a subsiding region, while the central mountains are probably rising. This is an excellent example of a plain formed by deposition, and due to the action of rivers. The great difficulty of navigation off the coast here, owing to the shifting sandbanks, etc., shows that the plain is being built out seawards. (After Rawling and Marshall's survey.) Scale about 10 miles to an inch.

mouths on account of the enormous amount of rock waste which their waters carry, which is thrown down when the flow of the river is checked as it enters the sea. Thus the Dee has so choked up its own mouth with sand that Chester is no longer a port. This suggests the method of plain formation by *deposition*, and the flat plain at the end of the Wirral, which is made land due to the action of the two rivers, the Mersey and the Dee, affords a good example on a small scale of such a plain. Such plains are chiefly due to the action of rivers; chiefly but not wholly, for on parts of our coast-line, *e. g.* on the coast of Northumberland, we find cliffs of boulder clay, now being worn away by the sea, so that their contained stones are scattered on the beach. This boulder clay is a deposit which was laid down by ice, and it is clear that at one time glaciers pushed their way into the shallow North Sea, and built up a coastal plain by laying down rock waste on its floor. Similarly, we saw that the Roman Campagna, once a shallow sea at the foot of the Apennines, was turned into a coastal plain by the deposition of showers of volcanic material over its surface (see Fig. 4, p. 12).

All these are examples of small coastal plains, but the eastern United States are fringed by a very wide plain which varies from a few to 60 miles in New Jersey, to 100 miles or more in North and South Carolina and Georgia, and is continuous with the coastal plain of the Gulf of Mexico, which in the vicinity of the mouth of the Mississippi has a width of several hundred miles. Another very wide coastal plain fringes the northern coast of Asia, and is continued into the plain of Europe.

The Atlantic coastal plain of the United States shows some interesting features. Like all plains it has a gently sloping surface, but when followed inland the angle of slope changes suddenly, the plain abutting against the Appalachian Mountains. American geologists give the name of Fall Line to this sudden change of slope, and it is interesting to note that a number of cities, *e. g.* Baltimore, Philadelphia, Washington, etc., are placed along the Fall Line. The reason is obvious. The coastal plain has wide, relatively slow streams flowing across it, and these streams are often navigable. The Fall Line, which marks the point where the streams leave the Uplands for the Lowlands, marks also the limit of their navigability.

Remembering what has been already said in regard to the Continental Shelf, it will be clear that this Shelf is but a submerged portion of a coastal plain, showing all the characters of a plain of marine denudation. The sea wears back the margin of the land and so forms a submarine platform. On this platform the waste brought down by the rivers is spread out, and slight movements of elevation may raise the plains so formed above the level of the sea, when they appear as coastal plains. Conversely a negative movement may depress the margin of the sea, and so permit its waves to attack new land areas.

Inland Plains.—There is no difficulty in seeing why we call the nearly uniform surfaces which sometimes fringe the shore, plains, but it is somewhat difficult to define an inland plain in such a fashion as to distinguish it clearly from a plateau. The actual height above sea-level is here not the determining feature, for the Great Plains of the United States are actually in places higher than the Appalachian Mountains, and are considerably higher than the Cumberland Plateau which lies to the west of those mountains. They are, however, much lower than the mountains and plateaux which lie to the west, and it is an essential part of the definition of an inland plain, that, whatever its height above sea-level, it should not be so high as any plateau or mountain in its own vicinity.

Such plains may also be divided into plains of deposition and plains of denudation, but as in the case of the coastal plains the distinction is rather in theory than in actual practice, for both processes may have been in operation at different times in the same plain. Excellent examples of inland plains of deposition on a small scale may be seen where rivers have, in whole or in part, filled up lakes. In the Alps, where lakes were once very numerous and are still abundant, all stages in the process may be seen, from the mere delta projecting into a lake, through the marsh with one or more lakelets on its surface, to the formation of the dry plain. A very pretty example of an early stage of the process is seen above Engelberg, where the little Trübsee lies in the middle of a small plain which was once its bed, but has been silted up by the rock waste brought down by the stream descending from the glaciers of the Titlis. The name of the lake suggests the turbidity of the water of this stream, and the sudden change of

slope causes its load to be deposited on the bed of the lake.

A further stage in the same process is shown by the plain on which Interlaken stands, which has been built up by the rock waste brought down by the Lütschine, and has separated an originally continuous basin into two parts, now called Lakes Brienz and Thun. Similar examples are frequent wherever lakes occur, it being the natural destiny of a lake to become silted up by the incoming streams and thus to form a plain.

An example on the large scale is furnished by the basin of Hungary, much of which was once a lake bed, but is now dry land, save for the large shallow lake of Balaton. Here the cutting through by the Danube of the mountain wall at the Iron Gates has permitted drainage to play its part in drying the original lake, in addition to deposition.

Similar plains tend to be formed by rivers wherever the rapidity of their flow diminishes, and are especially large where past or present glaciers have brought down much rock rubbish to be sorted and spread out by the river when in flood. The plain of Lombardy and the smaller plain of Piedmont are good examples, though in this case the first origin of the plain was the result of subsidence (*cf.* Fig 13, p. 40).

It frequently happens that large plains of deposition have arisen as coastal plains, and have been separated from the coast later by land movements. The plain of England was thus formed, and the Great Plains of the United States have apparently had a similar origin. All such plains of deposition are built up of horizontal or gently sloping beds, while plains of denudation may have their beds arranged at any angle.

This second type of interior plain, the plain of denudation, is theoretically always produced when any land surface remains for a prolonged period above sea-level. Any land surface is continually acted upon by all the agents of erosion, the first effect of which is to produce marked relief, hills and mountains being carved out of the harder rocks, while valleys and basins arise in the softer. But if the eroding agents continue to act for a prolonged period, then these inequalities are smoothed out or filled in, and what is called a peneplain is produced, a gently sloping surface, whose

slope is seawards. The term may, however, be applied to a much-worn plateau as well as to a plain.

As an example of a plain of denudation we may take the Midland valley of Scotland, which has been let down by a northern and southern fault below the level of the surrounding rocks, and has then been much worn by the denuding agents. Unlike the plain of England, which consists of young and mostly soft rocks, the Midland valley is built up of old and hard rocks, the hardest of which still stand up as ridges. But over the surface generally the glaciers of the Ice Age spread débris, so that deposition has played its part no less than denudation. The plain of Russia, which has been for a prolonged period above sea-level, and has remained unaffected by the crustal movements which have been so marked in other parts of Europe, is an example of the same phenomenon on a larger scale, as is also the plain round the margin of Hudson Bay in Canada.

To this brief account of plains we may add that from the human point of view they are the most important part of the earth's surface. Their low elevation allows rock waste to accumulate, and they are thus often fertile as compared with the barren high ground near them. On the other hand the want of a marked slope sometimes gives rise to difficulties in drainage, which may not be easy to overcome. In such cases, as we saw in the case of the Roman Campagna, the lower slopes of the adjacent hills may be much more fertile than the plain itself.

Another great advantage which plains offer is that communication over them is usually easy. Their rivers are generally slow and therefore often navigable, and the almost level surface makes the construction of roads and tracks easy, though here again imperfect drainage may give rise to difficulties. On the whole, however, it may be said that except where the climate is unsuited for human activities, plains are the most densely peopled parts of the earth's surface. As indicated above they may originate either by deposition or by erosion or by a combination of the two.

II. Plateaux.—Plateaux have been defined as tracts of land so situated as to appear high from at least one side, and having at the same time considerable areas at or near their summit levels. The plateau or Meseta of Spain is an excellent example. The southern edge of this plateau is formed by the Sierra Morena, which is in reality only the steep

scarp which marks the position of the boundary fault of the Meseta, and, despite the fact that it attains a maximum height of 7,900 feet, this range is strictly comparable to the Pennine Chain. Just as that chain faces the narrow plain of the Eden, so, on a much larger scale, does the Sierra Morena face the valley of the Guadalquivir.

It must be admitted, however, that the term plateau is used in a sense somewhat larger than is covered by the definition given above, for it is also applied to an area placed at a considerable height above sea-level, even if it lies lower than the surrounding areas; the plateau of Switzerland, already mentioned, being a good example. No hard and fast line can be drawn between plateaux and plains, but one distinguishing feature of the plateau is that its streams tend to flow in much deeper valleys than those of plains. This is a necessary result of the elevation, and it makes plateaux less suited as a rule to human life than are plains. For reasons which will be considered later, their rainfall is often lower than that of plains, and the deep valleys or canyons prevent the use of the streams for purposes of irrigation, make communication difficult by water, and offer a considerable obstacle to land transport. Plateaux tend also to be colder than plains in the same latitude. Their origin must be assigned to various causes. Sometimes a block of the surface has been elevated and subjected to long-continued denudation. In other cases the surrounding lands have sunk down, thus giving rise to the plateau, while in some cases they have originated by the pouring out of lava on the grand scale. These varied forms of origin are better considered under the heading of mountains, to which plateaux show many analogies.

III. Mountains and Hills.—Mountains and hills are portions of the earth's surface considerably elevated above their surroundings, the area of whose summit level is small in proportion to that of the base. Only rarely do conspicuous mountains occur singly; they are generally arranged in groups or series, a series of peaks being called a range. A collection of ranges forms a mountain chain, a somewhat deceptive term, for mountains do not occur in a straight row, but have usually a complicated arrangement. Mountains are distinguished by many peculiarities of climate, which greatly affect the vegetation and the fauna. They offer great obstacles to communication, not only from their

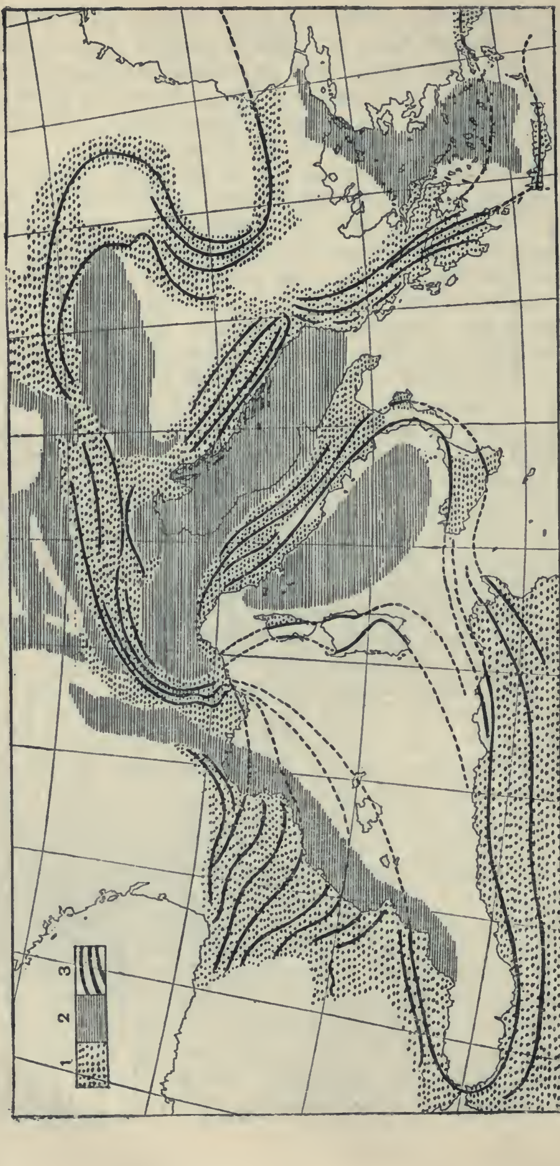

Fig. 13. Sketch-map of southern Europe to show the regions which underwent folding in Tertiary times. (1) The regions affected by the folding. (2) Regions which underwent subsidence when the folding occurred. Note especially the depressions of the lower Rhone valley, of the north Italian plain, of the plain of Hungary. (3) The lines indicate the direction of the folds. (In part after De Launay.)

elevation, but from the fact that they are intersected by deep valleys. As a general rule, therefore, they do not form very useful parts of the surface, though parts of their slopes are often heavily timbered, and other parts may bear rich pasturages. They display many varieties of form which in themselves are sufficient to show that they originate in many different ways.

1. *Folded Mountains.*—One of the most interesting types of mountains is that which is represented in Europe by the various chains which constitute the Alps, by the Apennines, the Pyrenees, the Sierra Nevada, the Balkan ranges, the Caucasus, and so forth, and is continued into Asia, where it is represented in the Tian Shan, the Himalayas, etc. All these mountains, which are sometimes

Fig. 14. Section across the Jura Mountains to show simple folded mountains.

The ridges coincide with up-folds (anticlines *a,a*), the valleys with downfalls (synclines, *s,s*). (From Geikie.)

said to constitute the Alpine system, have a common plan, and originated during the same geological period. Further, while this system is represented in North Africa by the Atlas Mountains, it has no representative in the great tract of land which stretches to the south of the Atlas and the Himalayas, and includes most of Africa, Syria, Arabia, etc., and the peninsula of India. If we give the name of Eurasia to the continental area which lies to the north of this line, and that of Indo-African region to the land which lies to the south of it, then we may say that it is characteristic of Eurasia, as contrasted with the Indo-African region, that its southern border displays a series of complexly folded mountain chains entirely absent from the latter.

Throughout the whole of what we have called the Alpine system, we find that the mountains not only display very marked relief, but that this relief is obviously connected with the folded structure. The diagrams (Figs. 14 and 15) show both how elaborate the folding is, and how close is the connection between the folding and the relief. In many cases the up-folds (anticlines) form the highest points, while the

down-folds (synclines) constitute the valleys. Into the details of the very complex folding we cannot go here, but it may be pointed out that this association of structure with surface relief shows that the mountains are of geologically recent origin. In folded regions which have for a prolonged period been exposed to the agents of erosion there is a tendency for the anticlines to become valleys and the synclines to become hills (*cf.* Fig. 17), because the resistance of the latter to the denuding effect of water is greater than that of the former.

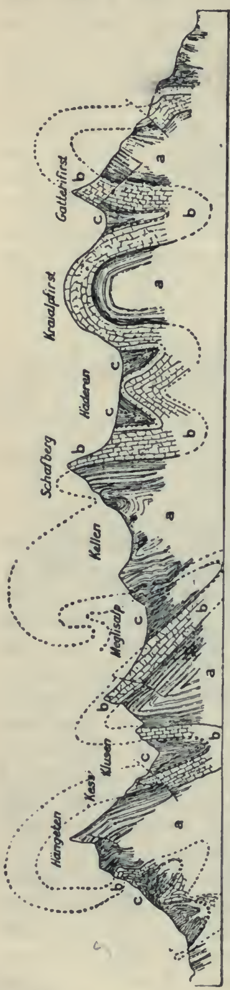

Fig. 15. Section across the Säntis Mountains, to show a more complicated type of folding than in Fig. 14. The dotted lines indicate the supposed original shape of the folds. (From Geikie, after Heim.)

We have already suggested the origin of this great system of mountains. The cooling earth diminishes in volume, and as it shrinks there is a horizontal push to which the weaker rocks respond by folding and crumpling. After they have been complexly folded in this way, a continuation of the lateral push forces them to rise above the surface as mountain chains, the formation of these being usually associated with the sinking of an adjacent land mass. In endeavouring to understand why the folding up of this great system should have taken place in the position in which it has occurred, we have to consider the nature of the rocks in the lands to north and south. Along the northern parts of Europe there stretch great masses of old and very hard rocks, found in Scotland and Scandinavia, and also in central France, southern Germany, and so forth. Similarly the rocks of the

Indo-African region are old, hard and resistant. Between these two areas lay once an enormous area of relatively soft rocks of recent origin. When great earth movements began during the period which the geologist calls Tertiary, horizontal pressure was exerted from south to north throughout the land mass formed by Eurasia and the Indo-African region. The resistant rocks to the north and south refused to yield to the strain, and the soft intermediate rocks were forced to buckle up, to become folded upon themselves, and thus to form some of the most majestic ranges on the surface of the globe at the present time. Similar movements occurred in the New World and helped to form the great mountain backbone of the American continent, though this partly owes its origin to other causes.

The mountains so raised were subjected to the action of the forces of erosion from the moment they emerged from the sea. At the present day, however, their form is not wholly due to the action of these forces, but in part to their structure, and we therefore call them Folded Tectonic mountains. This, then, is one mode of mountain building.

2. *Dislocation Mountains.*—Folded mountains, we have just said, are formed by the buckling up of relatively weak rocks, and old rocks offer extraordinary resistance to the forces producing folding. But however resistant they may be, there obviously comes a time when they can no longer withstand continued pressure. They then tend to snap across, in place of becoming folded up. This snapping across of rocks is called faulting, and is usually accompanied by the sinking of one side of the fractured beds. The result may be the formation of hills or mountains, as we have already suggested in the case of the Pennines. It sometimes happens that two more or less parallel faults occur near each other, when a block of rock may be isolated by the sinking of beds on either side. Such an elevated region is called a *horst*, but it must be realised that the apparent elevation is often deceptive, being due to the sinking of the adjacent areas. A sinking area sometimes cracks through in many places, and the fractured portions may settle down at different levels, and so give rise to the appearance of mountains or plateaux.

This is, therefore, another type of mountain, the dislocation mountain. Examples are frequent, though as a general rule dislocation mountains are much less imposing than

folded mountains. The region called the Morvan in France, really an isolated bit of the Central Plateau, is a dislocation mountain; so also are the Vosges (see Fig. 16), now separated from the Black Forest range, with which they were once continuous, by the deep fosse in which the Rhine flows. The granitic massif of Madagascar has had a similar origin, and so have part of the Rocky Mountains. Possibly the recently investigated Nassau Mountains of Dutch New Guinea have originated in the same way. They end in an enormous escarpment (see Fig. 12, p. 34), which extends over eighty miles at least and reaches in places a height of 10,000 feet. This, described by Captain Rawling as perhaps the most impressive feature of the earth's crust, is apparently a gigantic fault scarp, a region where movement has taken place.

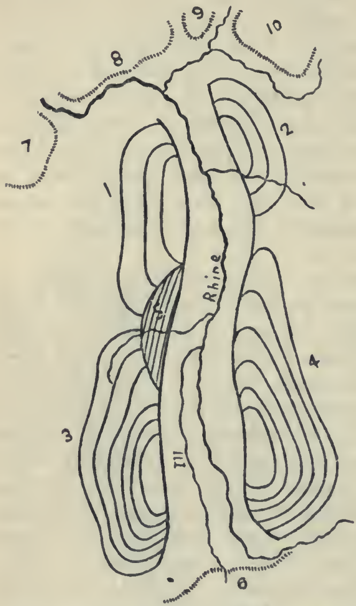

Fig. 16. The Rhine Valley, between Bâle and Mayence, to show the trough or rift in which the river runs.

(1) The Hardt, formerly continuous with (2) The Odenwald heights. (3) the Vosges, once similarly continuous with (4) the Black Forest. The lines are contours. The rift is bounded by two parallel faults, shown on either side of the Rhine valley. (5) is the depression of Saverne, (7) Hunsrück, (8) The Taunus, (9) The Vogelsberg and (10) the Spessart. (From Haug, after Schumacher.)

3, *Relict Mountains.* — The third type of mountains is constituted by Relict Mountains, this being an exceedingly common type. Such mountains owe their present form to denudation, and this is the essential point in their definition. Obviously, then, as an element in a classification, this type is less satisfactory than the preceding two. In their case we know something alike of structure and of origin,

but of the relict mountain we know only that it has originated in a particular way—of its structure we know nothing. In point of fact relict mountains are of very varied structure. Quite frequently they are the worn-down stumps of an old folded mountain chain (Fig. 17), but we cannot call them

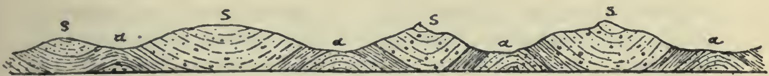

Fig. 17. Section across the Appalachian Mountains in Pennsylvania, which are relict mountains.

Here the ridges (*s,s*) coincide with the synclines and the valleys (*a,a*) with anticlines. (From Geikie.)

folded mountains because there is no present correspondence between their structure and their form. Similarly they may be worn-down horsts. Not infrequently they have originated in the simplest possible fashion by long-continued erosion of slightly inclined strata which have yielded unequally to the denuding forces (Fig. 18).

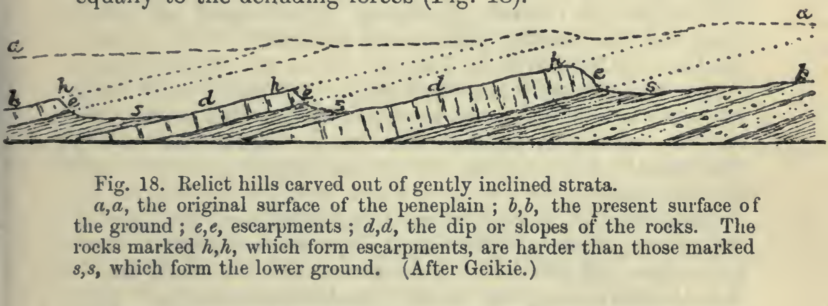

Fig. 18. Relict hills carved out of gently inclined strata.

a,a, the original surface of the peneplain ; *b,b*, the present surface of the ground ; *e,e*, escarpments ; *d,d*, the dip or slopes of the rocks. The rocks marked *h,h*, which form escarpments, are harder than those marked *s,s*, which form the lower ground. (After Geikie.)

The distinction has recently become of some importance in connection with the subject of palæogeography, that is, the reconstruction of the earth's surface at different geological periods. In attempting this reconstruction it is essential to be able to localise the upland areas of the different periods. If then we find a region, perhaps not now greatly above sea-level, but showing, in spite of the long-continued effects of erosion, remnants of powerful folding, then it is reasonable to believe that this area was once a mountain region. By a delicate process of reasoning, which it is not possible to follow here, Suess and other geologists have been able to settle the period when such worn stumps, which occur in

Scotland, in Brittany, in Cornwall, in Scandinavia and so forth, were towering mountain chains, and to show that just as the period which closed before the Ice Age was one of great earth movements, so also was the Palæozoic [1] period, and in it, as in the Tertiary [1] period, great mountain chains arose.

4. *Accumulation Mountains.*—A fourth type of mountain is the Accumulation Mountain, which owes its form to the way in which it is built up by the successive addition of materials. Examples on the small scale are sand-dunes and moraines, built up respectively by wind and the action of glaciers. More important from the topographical point of view are volcanic mountains, formed of material ejected from a volcanic vent, which may reach an enormous size. Before giving some examples of these it may be well to note that not all hills or mountains in which volcanic materials appear are accumulation mountains. For example, in Scotland, whose rocks on the whole are older than those of England, there are at the present day not a few conspicuous hills, made of volcanic materials, which stand up boldly from the surrounding plain. Of such are Arthur's Seat, the Binn of Burntisland, Traprain Law, etc., hills which if of no great height are conspicuous on account of their position. But these must be classified as relict mountains, for they owe their present form to denudation and not to their mode of formation. They are volcanic stumps, and not volcanoes.

Examples of accumulation mountains due to volcanic action are Orizaba (18,200 feet), Popocatepetl (17,523 feet), Aconcagua (22,860 feet), Chimborazo (21,498 feet), and a host of others, large and small. Such mountains have often a very symmetrical shape, and though they may reach a great height, as the figures suggest, differ from folded mountains in their tendency to occur as isolated peaks and not as ranges. Even these mountains, however, though definitely mountains of accumulation, may owe all the details of their topography to degradation.

5. *Laccoliths.*—A final type of mountains is of geological rather than geographical importance. These are the so-called Laccoliths. Laccoliths are mountains produced by the swelling up of the surface owing to the intrusion of lava from below. Typical examples are the Henry Moun-

[1] For explanation of these terms, *see* Appendix.

tains, Utah. In these cases the rocks overlying the lava are generally softer than is the lava, and are specially liable to denudation from the way in which they are bulged up. They tend, therefore, to be rapidly worn away, so that ultimately the igneous rock will protrude at the surface. It is probable that some of the conspicuous masses of igneous rock to be found in parts of Scotland and northern England once formed laccolith mountains, and have been subsequently exposed by denudation.

To sum up, then, mountains arise in five ways—

1. By folding, *e. g.* the Alps.
2. By the dislocation of rocks, *e. g.* the Vosges.
3. By denudation, *e. g.* the Grampians.
4. By accumulation, *e. g.* volcanic cones, such as Orizaba.
5. By the intrusion of deep-seated volcanic rock and consequent up-swelling of the surface, *e. g.* the Henry Mountains.

Negative Relief Features

The negative features of the earth's surface include valleys and basins. Of the valleys, very many are due to the erosive power of water, and fall to be considered under the head of rivers. According to many authorities, also, a considerable number of lake basins are to be ascribed to the erosive action of ice. Other basins owe their origin to such simple causes as local subsidence, due to the fact that underground water has removed certain deposits in solution, or are the result of volcanic action. But the fact that basins and valleys occur on the sea bottom, at depths which exclude the hypothesis that they can be due to the action of water or ice, shows that earth movements can produce such features. Such basins and valleys also occur on land surfaces, though there they naturally undergo an amount of modification by the forces of erosion, which is excluded in the case of submarine depressions. The basins are often of great importance, for from their position within areas of greater elevation than themselves direct drainage to the sea is often excluded, and they become regions of internal drainage. Among them are included the most useless, from the human point of view, parts of the surface.

I. Basins.—The Hungarian basin already mentioned is an example of a basin which does now drain to the sea, and is of great fertility. It was formed by subsidence (*cf*. Fig. 13, p. 40), and was once covered—at least to a large extent—by water. But the relatively high rainfall of the region, combined with the head of water produced by the extensive lake, permitted the Danube to cut a gorge through the mountain zone which separates the plain from the sea. This led to the draining of a great part of the plain, while deposition has shallowed the lakes which remain. In marked contrast with this region are such areas as those of the Tarim basin in Asia and the Turfan depression in the same continent; the region of the Sahara in North Africa; the region of the Great Basin in the western United States, and so forth. None of these drain to the sea; none has a high rainfall. In not a few cases the bottom of the depression is below sea-level, and running water has thus no power to establish the normal relief of the surface. The rivers are badly defined, and imperfectly fed by the insufficient rainfall. The surface therefore shows a uniformity which is in striking contrast with that of most land surfaces, and a desert topography speedily establishes itself. Such basins of inland drainage are estimated to cover about one-fifth of the existing continents, and they seem to show a tendency to spread rather than to diminish. Though they resemble plains in their low relief, they are markedly contrasted with plains in regard to suitability for human habitation. As a recent investigator points out, they illustrate the condition into which the whole of the earth's surface would ultimately be reduced if there were no crustal movements to give back to the rivers the power of erosion which is lost when any tract is worn down to the condition of a peneplain.

All such regions carry small populations. In the absence of any considerable amount of running water, wind is the chief erosive agent. A very large belt from which no water finds its way to the sea stretches across northern Africa into Asia, and includes the Saharan desert, the Arabo-Syrian desert and the Irano-Armenian desert. This region is characterised by the one-humped camel and the date-palm, is the home of the Arabian peoples and the great stronghold of Islam.

II. Valleys.—Valleys formed by earth movements are called rift valleys. They are bounded by lateral faults,

between which a portion of the surface has been let down, and are characteristically long in proportion to their width. By far the most impressive example known is the Great Rift valley of Syria and eastern Africa. The enormous fosse formed by this series of dislocations abuts at its northern end against the Taurus Mountains, then forms the depression between Lebanon and Anti-Lebanon, the Sea of Galilee, the valley of the Jordan, and the great hollow in which the Dead Sea lies. It is then continued into the Gulf of Akaba and the Red Sea, whence it enters the African continent, runs to the east of the Abyssinian escarpment, and forms the great depression in which lie Lakes Rudolf, Baringo, Naivasha, Manyara and Nyassa, as well as some smaller ones, finally ending near the Zambesi. From the northern end of Nyassa a branch rift valley, marked by Lake Leopold, turns off to the north-west, and is continued, through the long narrow valley in which Lake Tanganyika lies, into the valley of the White Nile. The whole depression extends for over 3,000 miles, and its borders are marked alike by steep scarps and by the presence of volcanoes, active or but recently extinct.

Minor Rift valleys occur at various parts of the earth's crust. For example, the Rhine runs in such a rift between the Vosges and the Black Forest (see Fig. 16), and the Midland valley of Scotland has been made by the letting down of a block of land in similar fashion. As a general rule, however, it is only where earth movements have been recent that the striking feature of a great cliff standing up at the side of a narrow, deep depression is present in the simple form in which it is to be seen in some parts of the Great African Rift valley.

In addition to such Dislocation valleys, another type which arises independently of erosion is the Synclinal valley, for which see p. 76.

Before, then, we proceed to consider in a future chapter the action of the forces of erosion upon the surface, it is necessary to make clear here that not all land forms owe their origin to these causes. It is true generally that the contrast between the smooth forms of relief visible in the great ocean depths and the sharp relief of land surfaces (*cf.* p. 20) is due to the fact that the forces of erosion act upon the latter, but not upon the former. But we have to note first that in basins of internal drainage running water has but little

power, and the important forces are atmospheric—moving air and temperature variations. Such agents produce a far less accentuated relief than does running water.

The second important point is that certain land forms owe their present shape, at least largely, to earth movements, and not to the process of erosion. Thus, while in any given case a huge scarp or cliff may be the result of erosion, it may also, as in the case of the Abyssinian scarp and probably the scarp of Dutch New Guinea, be the direct effect of faulting, with movement along the line of breakage.

Origin of Ocean Basins

One other point is of great importance. Apart from the effects of erosion, there is no fundamental difference between the relief of the land and that of the ocean floor, for those basins and rifts which occur on the sea bottom can also be recognised on the face of the land. This has a very important bearing upon the problem of the permanence of ocean basins. According to the older view, the great ocean basins were formed, once for all, at a very early period of the earth's history by a type of movement which has not repeated itself since. According to this view, subsequent earth movements have only affected relatively shallow seas —those about the margins of continents (the Continental Shelf). But the proof of the existence of great rifts on the surface of the land seems to show that earth movements on the grand scale are still going on. Not long ago, as the geologist counts time, land stretched across the northern border of the Atlantic from Europe to America, and the present North Atlantic has been formed by the foundering of this region. Similarly, at more than one period land has stretched from India through Africa to Brazil; the Indian Ocean and parts of the Atlantic having been formed by the sinking of these areas, owing to the formation of north-to-south faults. Indeed, the Great Rift valley of Africa may be regarded as threatening to form a new area of ocean, by rupturing another land mass.

CHAPTER IV

THE MATERIALS OF THE LANDS

The Soil and Sub-soil: (1) Local or Sedentary Soils, Peat and Laterite as Examples: (2) Drift or Transported Soils.—Loess, its Characters and Origin.—Boulder Clay.—Contrast with other Clays.—The Origin of Sedimentary Rocks.—The chief Types.—Igneous Rocks.—Metamorphic Rocks.—Classification of Rocks.

THE SOIL AND SUB-SOIL.—Except over limited areas the component rocks of the earth's crust are not exposed at the surface, but are covered by a mantle of varying thickness—the soil. As this consists of fine particles, easily transported by water, wind and ice, it tends to accumulate on the low grounds, and to be thin or even absent over high grounds and sloping regions. The existence of uplands and lowlands is therefore of great importance from the point of view of agriculture, for it is the presence of the former which permits of the development of a thick mantle of soil over the latter. The usual depth of the soil in plains is an additional factor which helps to make these specially fitted for human occupation (*cf.* p. 38).

But if even the mountains and uplands have a more or less complete covering of soil, although the transporting agents tend to remove this from them rather than to convey it to them, it is obvious that the soil-making agencies must tend to act over the whole surface. In endeavouring to find out what these agencies are we may conveniently study a section of the outermost portion of the crust, as seen, *e. g.*, in a quarry.

Here we notice, first, the existence of a covering of vegetation, probably grass, whose roots are deeply embedded in the soil. The fact that the roots ramify through the soil shows us that this is necessarily porous, while the further fact that the roots may belong to annual plants which die every year shows us that particles of decaying vegetable matter must be found throughout. Again, as roots are parts of living organisms and must breathe, it is clear that

oxygen must be reaching even the deeper layers of the soil.

But if in our quarry section we follow the soil downwards for a distance which varies in different regions from not more than a few inches to two or even, in well-cultivated land, three feet, we find that a change occurs. The mantle is here finer grained, much more compact, paler in colour, and more or less mingled with stones. The difference in colour, which is often very striking, is due to two distinct causes. In the first place, this sub-soil, as it is called, has very little decaying organic matter, or humus. In uncultivated land the humus of the soil is obtained from the natural decay of previous generations of plants; in ploughed and cultivated land it is supplied in some form of manure. Mild humus, as found in ordinary soil, is black in colour, and therefore its presence in the soil makes the latter darker than the sub-soil. The second cause of the colour difference is the fact that air does not penetrate freely to the sub-soil. Gardeners commonly describe the sub-soil as "bad-coloured," meaning that, as compared with the dark soil of the rich garden border, it is yellowish in tint. This is due to iron salts, which in the upper layers are completely oxidised, and so bleached.

Another difference between soil and sub-soil can only be ascertained by analysis, and this is that the soil is richer in the organic salts required by plants than the sub-soil, because these are being continually brought to the surface by the deeper roots. Obviously, however, there can be no hard and fast line between the two. Two agents especially are continually tending to produce intermixture. These are, first, the deeper roots, which penetrate the sub-soil, and, second, the earthworms, which burrow deep in cold or dry weather, and subsequently discharge at the surface fine particles brought from below.

Below the sub-soil lies the rock. In our quarry section it will be seen that the stones of the sub-soil increase as we approach the solid rock, whose uppermost layer is a shatter belt, where the solid rock has been greatly altered and split up by the action of percolating water. Obviously, then, in such a case the soil has been formed by the gradual decomposition of rock *in situ*, plus the remnants of countless generations of plants which have lived and died at the surface. Such a soil is called local or sedentary, the essential

point being that it owes its origin primarily to the underlying rock, and displays generally the characters of that rock, *e. g.* a sandstone will give rise to a sandy soil, one rich in silicates of alumina to a clay soil, and so forth.

In not a few cases, however, the soil may contain elements obviously not derived from the rock which it overlies; and the same type of soil may be very widely spread and uniform despite variations in the underlying rock. Such soils have been brought from a distance, and are called transported or drift soils. We may give one or two examples of both types.

1. *Local or Sedentary Soils.*—*Peat* and *Peaty Soils* are sedentary types very widely spread in the colder and damper regions of the globe, especially in the northern hemisphere, where land masses are most extensive in high latitudes. The essential condition for their formation is that the climate should be cold and the surface waterlogged. The latter condition may be obtained by the wetness of the climate or by the presence of an impermeable substratum. The cold climate diminishes the rapidity of chemical action; the waterlogging prevents the access of free oxygen. The result is that only anærobic bacteria, that is, those which can live without air, exist, and they decompose vegetable matter very partially, forming acid humus or peaty matter, which is very unfavourable to the growth of most plants. In such soils there is often a hard layer some little distance below the surface, called *pan* or *moorpan.* This is composed of hydrated oxide of iron (limonite), and effectually prevents the access of air to the lower layers, and also drainage of the surface. The first step in the reclamation of such soils is to break up the pan. As the iron has been carried down from the surface, it is usual to find pure white sands (*i. e.* sands which have lost all their iron compounds) associated with the dark peaty soils, the colour contrast between the two being very marked.

Laterite is a red earth as characteristic of damp tropical regions as is peat of damp cold regions. It occupies large areas in India, Africa and South America, and is often somewhat infertile, while its tendency to harden makes it difficult to work. It is the result of the decomposition *in situ* of rocks, and is rich in iron, sometimes so rich that it is worked as a source of iron. But though primarily sedentary, it may be transported by running streams after its formation, and on, *e. g.*, the Deccan of India forms layers

of enormous thickness. The exact causes of its formation are somewhat obscure, but the great activity of chemical change in a warm humid climate is apparently an important feature, as is also the absence of frost, which has a markedly pulverising effect on the soils of lower latitudes. Laterite arises from the decomposition of a considerable variety of rocks, and is rich in alumina as well as iron, but poor in lime.

2. *Drift or Transported Soils.*—Of the transported soils *Loess* is important, both on account of its great fertility and its wide distribution. It is very widely distributed in middle latitudes, its extension being marked by treeless belts, producing pasture in a state of nature, and rich crops, especially of cereals, when cultivated. Thus we find it forming a broad belt across Europe from Picardy through Poland into Russia, where it forms the famous wheat-lands. In Asia it covers all the fertile lands which fringe the central deserts and plateaux, and extends from Turkestan through southern Siberia to China, where it reaches a great thickness and has a vast extension. The civilisation of China, indeed, may be said to be based upon the loess. It reappears in the prairie regions of North America and in the pampas of the Argentine.

Its origin has been greatly debated, but it seems clear that wind has played an important part. The loess, generally speaking, occupies the zone near the southern limit of the glaciated region in the northern hemisphere, and to the south of it lies a zone of steppes and deserts. In the southern hemisphere it lies near the northern limit of glaciation, and has the steppes and deserts to the north of it. It is believed that at a period when steppe conditions were more widely spread in middle latitudes than at present, strong winds attacked the finer elements in the glacial débris, and deposited it over wide areas of the surface, where it was subsequently partially modified by water.

The loess has essentially the characters of a loam; that is to say, it consists of a mixture of sand and clay. It is excessively fine-grained, and is rich in lime. In a belt which stretches across Southern Russia the loess has a surface layer rich in humus. This, the famous Black Earth zone is extraordinarily fertile, all the favourable conditions in a soil—fine texture, presence of lime and mild humus—being simultaneously present. The origin of this deposit seems to have been as follows. Russia has been a land

surface for a prolonged period, but at one time much of its surface was covered by lakes. These gradually silted up, partly owing to the growth of marsh plants. As the water slowly dried up the marsh plants decayed, and their residue formed the thin surface layer of mild humus, the presence of lime in the underlying soil preventing the formation of acid humus.

As loess is an example of an æolian or wind-borne deposit, so *Boulder Clay* may be taken as an illustration of a transported soil owing its origin to the action of ice. It is widely distributed in the more northerly parts of Europe, including the British Isles north of a line between the Thames and the Severn, and is a tough unstratified clay, usually loaded with stones. It may be many feet in thickness, and only the upper few inches have undergone such modification as to form a true soil. The clay varies considerably in composition, according to the rocks from which it has been derived, but as a rule clay soils are difficult to work, and are liable to become waterlogged, owing to their impervious nature.

The term clay is applied to fine-grained deposits, which become plastic when wetted, and contain considerable amounts of silicates of alumina. Boulder clay, as found in northern Europe, is apparently the remains of the ground moraines of glaciers of the Ice Age, and consists of little-altered rock-flour; that is, it was chiefly formed in a mechanical fashion by the mere wearing away of rocks. Other clays, *e. g.* the kaolin or China-clay of Devon and Cornwall, have had a different mode of origin. They consist chiefly of the insoluble residues of rocks, *e. g.* granite, which have undergone extensive chemical alteration. Such clays, therefore, form good examples of the third type of transported soils, the alluvial deposits, which owe their origin to moving water. Such soils may be merely disintegrated rock, *e. g.* a calcareous sandstone if acted upon by rain water would form a sandy alluvium, the calcareous cement being carried away by the water in solution. On the other hand, as in the case of the alluvial clays mentioned, the rocks may undergo profound chemical change, the solid residue being laid down by water as an alluvial deposit.

There are many types of alluvial soils, for running water acts more universally than wind or ice as a soil-transporter.

Without going into details, we may note that a loam is a combination of sand and clay, a marl a mixture of clay and lime. Pure sand consists of particles of quartz, and is a most infertile soil, though the addition of sand to clay greatly improves the value of the latter. Clays, muds and silts are often rich in plant food, especially when derived from igneous rocks.

The Origin of Sedimentary Rocks.—This cursory treatment of soils and sub-soils enables us to draw some general conclusions as to the various types of rock found on the surface. We see wind, water and ice continually transporting rock rubbish from one region to another, and we note how their load tends to accumulate on low ground, and especially in shallow water, whether on the sea-margin, or in lakes, or at the sides of rivers. But we have seen also that the earth's crust is continually undergoing movement of elevation or of depression. We have seen, for example, in a general way that such regions as the plain of Hungary, the plain of Lombardy and the Great Plains of the United States are once depressed regions which have been raised above sea-level. When they were in process of slowly subsiding load after load of rock waste would be deposited upon them, and the lowermost deposits would be exposed to enormous pressure. We can well understand, then, that loose deposits of silt and mud would become converted into such rock as shales; that beds of sand, owing to pressure and the infiltration of water carrying cementing substances, would form sandstones; that beds of gravel and shingle would form conglomerates and grits, and so forth. A great number of the rocks now exposed at the earth's surface have been formed in such a fashion, and constitute what we call the Sedimentary or Derived rocks; sedimentary because they have for the most part been deposited as sediment in water, derived because they are formed from the waste of pre-existing rocks. They are also called stratified rocks, because most show an arrangement in layers or strata, due to their mode of origin, and fragmentary because they may often be seen to consist of fragments of older rocks. A conglomerate or pudding-stone, for instance, is like a solidified bed of shingle or gravel, and contains obvious fragments of other rocks.

We have already mentioned in shale, sandstone, conglomerate and clays some common types of Derived rocks,

but we must add a note on one or two other important types. All those mentioned are formed by mechanical agencies—wind, water and ice, but there are two other common modes of formation. For instance, we have all seen the stalactites and stalagmites found in caves, formed by the evaporation of water containing carbonate of lime. A somewhat similar substance is often deposited from streams in limestone districts, and when very hard forms travertine or tufa, a hard compact substance extensively used as a building material, *e. g.* in Rome. Again, the water of salt lakes is loaded with common salt, and when this water is exposed to evaporation great deposits of rock salt may be thrown down. Both of these are examples of chemically-formed Derived rocks. Again, some rocks are either due to the activities of living organisms, or are formed in greater part at least by their remains. Among the most important of these rocks are the different kinds of limestones (see p. 99), which consist largely of carbonate of lime, and contain the hard parts of lime-containing organisms, *e. g.* the shell of molluscs, the skeleton of corals, and so forth. When perfectly pure, limestones are completely dissolved by water containing carbonic acid, but most limestones contain a good deal of earthy matter which is left behind when the lime is removed. The presence of limestone has often an important effect upon the topography, a fact which we must consider later, and also upon the plant covering.

Among other important organically-formed rocks are lignite or brown coal, ordinary coal, anthracite or mineral coal and jet. All these owe their origin to plant remains, and their presence at particular parts of the surface may be of great importance in human life.

Other substances which are technically rocks are mineral oils, such as petroleum. This is apparently formed by the destructive distillation of organic matter. Animal and plant remains are deeply embedded in deposits which have been heaped up around them, and they are there subjected to heat. This heat drives off the volatile constituents in the form of oil, which accumulates under pressure in cavities of rocks. If these cavities are tapped the oil escapes at the surface in springs, as for example at Baku in the Caspian area and in Pennsylvania. Mineral gas, which is abundant in parts of the United States, seems to be produced in a similar fashion.

Igneous Rocks.—The next great group of rocks consists of the Igneous rocks, those which owe their origin to subterranean forces. These doubtless, no less than the last, are derived from pre-existing rocks, but the point is that when ejected at the surface it is impossible from their appearance to say from what rocks they have originated. Many are crystalline, it being noticeable that those which have consolidated at great depths contain large crystals, *e. g.* granite, while lavas which consolidate at the surface may contain a large amount of glassy matter. One of the great interests of Igneous rocks is the fact that they may contain crystals of a great variety of minerals, some of which are of much economic importance, and they often have associated with them valuable mineral deposits. Such ores may occur diffused through the rocks, as is frequently the case with copper, or they may be washed out of such rocks and accumulate in masses in river gravels, etc. Gold and tin often occur in this way, the deposits being called *placers*. Again, as Igneous rocks cool, cracks or veins form in them, and these veins may be filled up with mineral deposits, derived by percolating water from the rock itself. Such lodes or veins also occur in Derived rocks, and among the minerals found in them are lead, iron, etc.

Metamorphic Rocks.—The third and last type of rocks consists of the so-called Metamorphic rocks. These are rocks which have been formed by the alteration either of Derived or of Igneous rocks, owing to the action of pressure and heat. They differ from igneous rocks and resemble superficially the secondary ones in that they show an arrangement in thin layers. These are called folia, and the rocks are said to be foliated. These layers, however, differ markedly from the beds in which Derived rocks are arranged. In the latter case the bedding corresponds to the layers in which the rocks were laid down, but the foliation is a secondary and superinduced structure, due to the great pressure to which the rocks have been subjected. It has been compared to the layers which appear in pie-crust as the result of the rolling which it undergoes in the course of making. Metamorphic rocks are usually very hard, and tend to form uplands owing to the great resistance which they offer to denudation. This is also true of some of the Igneous rocks, the compact types being very resistant. The Derived rocks on the other hand are often readily weathered,

one cause being the fact that the bedding planes, and the fissures called joints, which tend to run at right-angles to these, allow free passage to water, which affects the rocks both chemically and mechanically.

The above classification of rocks may be represented in tabular form as follows—

I. Derived Rocks—
   1. Mechanically formed, *e. g.* sandstone and conglomerate.
   2. Chemically formed, *e. g.* travertine and rock salt.
   3. Organically formed, *e. g.* coal and limestone.

II. Igneous Rocks—
   Examples: granite, basalt, obsidian or volcanic glass.

III. Metamorphic Rocks—
   Examples: gneiss, mica schist, slate.

REFERENCES TO SECTION II.

Of the numerous large books on the general subject of Physical Geography the following may be mentioned: De Martonne, *Traité de Géographie Physique* (Paris, 1909), with very copious references and excellent illustrations and maps; Salisbury, *Physiography* (London, 1906), which is relatively full in regard to the land, but treats the other divisions of the subject more briefly; de Lapparent, *Leçons de Géographie Physique*, Third Edition (Paris, 1907), important because it describes the various parts of the world from the physical point of view; Supan, *Grundzüge der Physischen Erdkunde*, Fifth Edition (Leipzig, 1911).

The full significance of topographical maps can only be appreciated by their use. Ordnance Survey maps can be obtained at most booksellers, and in quantities at a cheap rate for schools on application to the office at Southampton. In using them such books as Reeves, *Maps and Map-making*, and Close, *Geographical and Topographical Surveying*, will be found useful. An excellent volume devoted to the U S.A. maps is *The Interpretation of Topographic Maps* by Rollin Salisbury and Wallace Atwood (Government Printing Office, Washington, 1908). Large-scale maps of many countries can be obtained from Stanford, London.

For the form and structure of the lands, reference should be made to books on geology, *e. g.* Geikie, *Outlines of Geology*, several editions, and *Structural and Field Geology* (Edinburgh, 1905). On the physical side of geology there are many interesting French books, notably, de Lapparent, *Traité de Géologie*, several editions; de Launay, *La Science Géologique*, (1905), and Emil Haug, *Traité de Géologie*, the last in several volumes, completed in 1911. Suess's great work, translated as *The Face of the Earth*, will be found difficult by the beginner.

The soil is a subject of great importance in geography, the standard work being Hall, *The Soil* (London).

SECTION III—THE AGENTS WHICH MODEL THE LAND

CHAPTER V

THE WORK OF THE ATMOSPHERE AND OF GROUND WATER

The Action of the Atmosphere.—Wind.—Ground Water.—General Effect of Surface Agents.—Springs.—Origin of Rivers.

The Action of the Atmosphere.—We have discussed in general terms the Relief Features of the surface, and the main characters of the materials of which the crust is composed. We have now to consider in a little more detail the agents which are continually at work modifying the surface. So far we have merely alluded to the processes of degradation and deposition which are continually going on, but it is necessary to consider these, and especially the action of running water, in more detail, for it is to the forces of denudation that all the minor features of relief owe their origin.

The first point to be considered is the action of the atmosphere. Air contains, as we all know, free oxygen, and it contains in addition varying amounts of carbonic acid. It also carries a greater or smaller amount of water vapour. Because of the presence of free oxygen it acts as a strong oxidising agent. It is a common experience that objects made of iron when exposed to damp air oxidise, or rust. Now iron is one of the commonest rock constituents, and is present in greater or smaller amounts in almost all rocks. The fact that it tends to become oxidised in the surface layers of rocks, disintegrates these layers, and is one of the factors in the series of changes which we call weathering. Similarly, the presence of carbonic acid in damp air permits the formation of carbonates in exposed rock surfaces. These are but two examples of the varied kinds of chemical change which tend to occur in rocks exposed to the atmosphere.

Again, as we shall have occasion later to show in more detail, the atmosphere undergoes great temperature variations, both diurnal and seasonal. Most substances expand with heat and contract with cold, and the alternation of these processes, often aided by the freezing of films of water between rock particles, helps to disintegrate rocks.

In these cases it is the exposure of the rock surface to the action of the atmosphere which is the essential point, and therefore weathering takes place most rapidly where the disintegrated layer is removed as fast as it is formed, so that a fresh surface is exposed. This happens especially on steep slopes, such as occur on mountains, at the sides of valleys and on the sea-shore. On mountains the process is very conspicuous, and cliffs generally show at their base a talus slope, that is a long slope of débris riven from the cliff face above. Such talus slopes are composed of angular blocks of all sizes, and often rest at a very unstable angle, so that a touch will send the whole mass sliding down the mountain slope. The lower portions of the slope sooner or later, however, come to rest and may then be overgrown with vegetation, which increases the stability of the whole.

The summits of lofty mountains, when the slopes are too steep for snow to lodge, are often completely covered with rock rubbish, including huge blocks torn off by the frost. Where glaciers are present, however, much of this débris is sooner or later carried away and spread out upon the low ground.

Wind.—Moving air, as we have already seen, may cause great accumulations of fine rock waste, well exemplified in the case of loess. In addition to forming horizontal deposits of this kind, the wind may build up dunes or sand-hills. The beginning of these is always some slight obstacle which checks the velocity of the wind, and causes it to throw down its burden. The sand grains are dropped on the near side of the obstacle, and the result is that sand-dunes tend to have a long slope on the windward side, and a shorter, steeper one on the leeward side. Such dunes are often migratory, and may progress inward from the shore and so destroy cultivated land.

But in addition to acting as a depositing agent in this way, wind, especially in arid regions, is a denuding agent. By means of the load of sand or dust which it carries it acts like a sand-blast, wearing away the rock surfaces

against which it impinges. The peculiar and fantastic rock forms often found in desert regions owe their origin to this cause.

Ground Water.—But important as the atmosphere and wind are, they are generally less important than water, whose action we must next consider. With the exception of some intensely arid regions, where rain never falls, every part of the land surface receives a certain amount of water, which reaches it either in the form of rain or snow. The latter, as we shall see, in regions where only partial melting occurs, finds its way down the slopes in the form of glacier ice. Rain water falling on a surface has one of two possible fates; it may run off at once, forming streams and runnels such as we see forming on hard surfaces, or it may sink in. In the latter case it forms ground water, and, owing to the various acids, etc., which it absorbs during its passage, it has very important chemical effects upon the rocks with which it comes into contact. It may oxidise or deoxidise, it may carry away materials in solution, it may form carbonates, it may modify minerals by combining with them in the chemical process called hydration. It is this percolating ground water which produces the alterations we noticed in the quarry section in rock surfaces protected by superficial deposits, and to its power of percolation it owes a much more active chemical action than can be carried on by the atmospheric air, whose sphere of activity is much more limited.

Effect of Surface Agents.—These varied agents, frost and heat, the chemical action of moist air, the effect of wind, rain and percolating water, act in various combinations and produce the phenomenon called the weathering of rocks. All rocks exposed to the weather or to percolating water are modified to a greater or less extent, however unaltered they may appear to be, and from all exposed surfaces not only are stones and boulders rent off, but an enormous quantity of fine powder and dust is liberated. Where the climate is arid, as already suggested, this dust forms desert sand, and is transported chiefly by wind. Here the paucity of water makes chemical change slow, and there is thus a tendency for rocks to disintegrate mechanically into small particles, rather than to undergo the chemical changes which give rise, *e. g.*, to clay, by the decomposition of some of their constituent elements. Again, in the desert regions plants do

not grow freely, and thus there is little or no humus formation. With the absence of humus those intricate chemical changes which occur in soil are absent, and we have desert sand as contrasted with the soil which covers most other regions. But whereas sea-sand consists of almost nothing but grains of quartz and particles of shell, etc., the fact that plants will often grow freely in desert sand if water is supplied shows that the necessary elements of plant food are present there.

In damp regions the finer rock waste is washed away by the rain, and sooner or later finds its way into the rivers and streams, where, carried about by the rushing water, it becomes a potent agent in the disintegration of the rocks forming the banks of the streams.

The larger blocks and stones torn by frost and sun from the mountain sides are to a certain extent carried by floods into the mountain torrents. Where this does not happen directly they undergo further weathering as they lie on the talus slope, owing to the fact that all their surfaces are now exposed to the denuding agents. They thus form a further supply of the finer forms of rock waste for the streams. In brief, weathering furnishes the streams with the weapons which they use to scour out, deepen and widen their beds.

The above description applies to the majority of rocks and deposits, which are either so permeable as to permit the water which falls upon them to sink in, or sufficiently firm to permit of the formation of permanent watercourses. Deposits do occur, however, which are at once impermeable and excessively unstable, clays and marls being examples. In these cases a very peculiar form of weathering is often produced, especially if the climate or other causes prevents the formation of a complete covering of vegetation. In such cases the soft surface, when acted upon by water, gives rise to an infinite number of runnels and gutters, all more or less impermanent in character, from the way in which the beds slip so soon as a certain slope is reached (see Fig. 33). A typical "badland topography" may thus be reached, as exemplified in the arid lands of the western United States. Similar topographical forms occur frequently in the Apennines when clay lands are deforested, and the formation of an infinite number of runnels separated by crests renders the land entirely useless. A modification of the same type of topography is often seen in regions where

glacial deposits are abundant. The clay of which the deposits consist is worn out into ridges and narrow valleys by the action of the rain, the stones which are freely scattered through the deposit protecting the clay immediately beneath each, so that so-called earth pillars or pyramids are formed, the column of clay being capped by a large stone. These are not infrequent in the Alps (*e. g.* near Botzen in the Tyrol), but are not confined to glacial deposits, for any loose material containing harder nodules—*e. g.* some volcanic deposits—may give rise to earth pyramids in the same way.

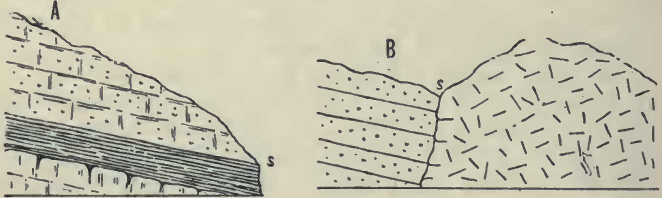

Fig. 19. Diagrams to illustrate the Origin of Springs.

In A the upper beds are permeable, so that water sinks through them, to be stopped eventually by the shaded beds, which are impermeable. The water then runs along the upper surface of this stratum down the line of the dip, and appears at S as a spring. In B the left-hand beds are again permeable, and water percolates through them and runs along the line of the dip; these beds, however, abut upon a mass of crystalline rock (to the right) which is much less permeable, the water is consequently forced by hydrostatic pressure to rise along the line of the fissure between the two kinds of rock, and appears at the surface at S as a spring.

Springs.—But before passing on to consider the action of streams, we must mention another point of interest about percolating water, which is that it is for the most part destined to reach the surface again and to form or assist to form running streams. To the phenomenon of the appearance at the surface of ground water we give the name of springs, and we find that many rivers have their sources in such springs.

The diagrams (Fig. 19) will help to make clear the origin of springs. In the most general form we may say that a spring owes its origin to the percolation of water through a pervious bed of rock which lies upon or abuts against an impermeable one. The water, unable to travel further in

the direction in which it has been moving, flows out at the surface or is forced up under considerable pressure. In some cases full-grown rivers may rise suddenly from springs. This often happens in limestone districts. An interesting example is the so-called Fontaine de Vaucluse, near Avignon in France, where in wet seasons a large river issues from the foot of a limestone cliff. In this case rain water enters by a number of pits in the extensive plateau above, into what must be an elaborate series of fissures, ramifying through the limestone rock, and this water appears at the surface as a river at the base of the escarpment which marks the termination of the plateau.

Springs are of considerable human importance. They often determine the choice of a settlement by yielding a pure and abundant water supply. The rivers which they feed have frequently a steadier flow than those whose sources are superficial, for ground water is not so liable to evaporation as is surface water.

In some cases ground water occurs in rocks under considerable hydrostatic pressure, but cannot find an exit to the surface. In this case the water is obtained, sometimes in quantity, by boring, the water rising to the surface in the bore, and sometimes forming a fountain. Such bores are called artesian wells, and are often of great importance in furnishing water in arid districts. The necessary conditions are shown in the diagram (Fig. 20).

Perhaps we should add that it is not necessary for a bed of rock to be absolutely impermeable to water to cause a spring to arise. If a bed which is highly permeable rests on one which is only slightly permeable, then, if the conditions are favourable, a spring might arise at the junction, owing to the way in which the rapidity of flow of the water would be checked.

Origin of Rivers.—Rivers, as we have seen, may originate from springs, or from the union of streamlets, or from a combination of both. The streamlets, again, may originate in lakes, in swamps, from melting snow or from glaciers. However formed, the resulting rivers are the most potent of the agents of erosion, partly because of their very wide distribution. Except in arid regions, where, as we have seen, wind is the most active eroding agent, the minor land forms which we see everywhere are for the most part due to the action of running water. Even in limestone

areas, where no water may appear at the surface, its effects are visible, and the fact that it occurs underground profoundly affects the topography.

If this be so, then obviously the conditions presented by any given course of water are but temporary, can only be regarded as one of an infinite series—a single film, as it were, from a cinematograph roll. As the series is, theoretically, continuous, it should be possible to indicate approximately the position in the cycle occupied by any particular river. To the whole series of changes which

Fig. 20. Diagram to show the conditions necessary for the production of an artesian well.

The beds are basin shaped, and the unmarked rock at the surface is supposed to be impermeable. But the permeable bed (*a*) crops out at the surface laterally, as must also the permeable bed (*b*) beyond the limits of the diagram, and water enters at these outcrops and flows down the dip of the strata, where it accumulates in the beds (*a*) and (*b*), and is unable to find an outlet, the bed (*c*) being impermeable. If a bore be put down through the surface bed to either of the beds (*a*) or (*b*), water will rise in the borehole, and appear at the surface. If the bed (*d*), which is also permeable, crops out at the surface at some distant point, it will similarly become saturated with water, which cannot escape either above or below owing to the impermeable beds (*c*) and (*e*), and in this case a deeper bore put down to (*d*) would also yield artesian water, whose head or force of outflow would be greater than that of the previous bores.

every watercourse is believed to undergo during its existence the term *Cycle of Erosion* is applied, and early, middle, late, or young, mature and senile, are terms applied to the notable stages in the series of changes. Clearly, then, we can study rivers from two points of view. We can describe them as they appear in nature, using purely descriptive terms, or we can consider them as occupying a particular position in the cycle of erosion. We shall employ here both methods, beginning with the purely descriptive one, and passing on to consider what is meant by the cycle of erosion, and the method of determining the particular stage which a given stream illustrates.

The first point of interest is to consider generally the

distribution of rivers over the surface. As we have already noted (p. 48), the whole land surface does not drain into the sea. No less than one-fifth of the total area of the continents is included in the basins of internal drainage, *i. e.* in the regions from which not one drop of water finds its way directly to the oceans. This is a matter of some importance, not only from the human standpoint, but also in connection with what is called the base-level of erosion. A river has the double function of wearing away the land, and of forming new land by laying down alluvial deposits. As the denuding action depends upon gravity, no stream can lower the surface below the level of its own lowest point, *i. e.* where it enters sea or lake. This is, then, its base-level, and rivers tend normally to wear down the land to base-level. In the general case the base-level is the level of the sea, but basins of internal drainage form a marked exception. Where the lake which receives the drainage is above sea-level, then the region presents an exception to the rule that all land surfaces are tending to be worn down to sea-level. On the other hand, where—as in the case of the Dead Sea—the basin sinks below sea-level, then its incoming streams can excavate the land below sea-level.

The next point of interest is the nature of the water-parting, or watershed. In the Middle Ages it was believed that mountains always formed definite water-partings, and it was customary to represent a line of mountains in the middle of the continents, and to show the rivers running right and left from it. To some extent this notion still persists in the popular mind, and it is a good plan to trace the line of the water-parting on a map in order to realise its extremely irregular course, and the fact that it is far from corresponding to the crests of the high ground. In point of fact, as we shall see, divides are continually shifting, and as the rivers of any given continent may be of very different ages, and are all tending to encroach upon each other's territory, the watershed at any given period represents merely a temporary condition of equilibrium.

We may further point out that the fact that the Pacific has marginal mountain chains, while such chains do not occur around the Atlantic, gives the latter a much wider drainage area than the former. Population at the present day tends to concentrate round the areas which drain into the Atlantic, and this is associated with the length and importance of the rivers whose waters flow into it.

CHAPTER VI

THE WORK OF RUNNING WATER

The Rhone as an Example of a River.—Division of the Rhone into Regions.—The Upper Rhone.—Division of its Course into three Parts.—The Mountain Tract.—The Longitudinal Valley.—The Elbow of the Rhone and the Transverse Valley.—The Tributaries of the Upper Rhone.—The Formation of Alluvial Cones.—River Capture.—Origins of Longitudinal and Transverse Valleys.—Examples in the Jura.—Lake Geneva.—The Middle Rhone.—The Lake of Bourget.—The Lower Rhone.—River Capture in the Upper Isère Region.—Effect of Streams on Upland Regions.—Work of Rivers in General.—The Cycle of Erosion.

The Rhone as a Typical River.—In order to make the description of the work of a river more definite and precise, we may describe a particular river, choosing the Rhone,[1] the course of which is complicated and illustrates many difficult problems.

We may conveniently divide the course of the Rhone into three parts: (1) the Upper Rhone, from the source to the entrance of the river into Lake Geneva; (2) the Middle Rhone, the part included between the exit from Lake Geneva to the confluence with the Saône; finally (3), the Lower Rhone, from the town of Lyons to the entrance into the Mediterranean. Of these divisions the first two are remarkable for the peculiar bends which the valley shows, while the last is almost equally remarkable for the general straightness of the valley.

Course of the Upper Rhone (Fig. 21).—Beginning with the Upper Rhone, we may describe its course briefly as follows. The river arises as a considerable stream from an ice cave in the Rhone glacier, and for a short distance flows along a nearly level surface strewn with glacial débris, which represents a region covered by the ice only a very short time ago. On its course over this region the river is fed

[1] The maps on pp. 69, 79, and 82, together with the sketch-maps, illustrate the main points in this description. Details in the case of the Middle and Lower Rhone, are best studied in the French 1 : 200,000 Army map; sheet No. 54 is especially instructive.

Fig. 21. The Upper Rhone.

by tributaries coming both from the glacier and from springs. The combined stream then plunges with great rapidity down a wild and rocky gorge, which it has cut owing to the load of rock waste which it carries. Somewhat above the village of Oberwald it alters its southerly direction for a south-westerly one, and enters the wide valley of the Upper Rhone, whose presence gives the canton its Swiss name of Valais—*the* valley (see Fig. 22). This valley is broad and flat-bottomed, is bounded on both sides by lofty chains of mountains, and forms the natural boundary between the Bernese Oberland and the Pennine Alps. Such a valley, running parallel to conspicuous mountain chains, is called *longitudinal*, and from Oberwald to Martigny the Rhone runs in a broad, longitudinal valley. At Martigny, shortly after having received a powerful tributary, the Drance, the Rhone bends upon itself at a right angle, the "elbow" of the Rhone, and, breaking through the mountains at the narrow gorge of St. Maurice, runs north-eastward to Lake Geneva. As a glance at the map will show, the gorge of St. Maurice has been cut through what was once a continuous belt of high ground connecting the Dent du Midi with the Dent de Morcles. Here, then, the river valley is not longitudinal—rather has the stream cut a way for itself *transversely* across the mountains. Thus the Upper Rhone may be subdivided into first, a short mountain tract, where the stream follows the slope of the mountain massif, this massif feeding the Rhine from one of its sides, and the Rhone from the other. Next comes a wide, longitudinal valley, which, by an abrupt change of direction, opens into a transverse valley cut through the mountains. A great number of the Alpine rivers, including such tributaries of the Rhone as the Arve, the Isère and the Drac, show similar conditions in the upper parts of their courses, and the explanation is of much interest. But before proceeding to consider it we must discuss some other points in regard to the Rhone.

The portion of the river above Oberwald is running over very hard rock, which can be eaten back only slowly, despite the erosive force of the water. The longitudinal valley has been cut out partly by ice and partly by water, and its slope is much gentler than that of the upper reaches of the valley. The consequence is that in it the river, being less rapid, tends to deposit rock waste rather than to deepen its valley.

During its course down this part of the valley the stream receives many tributaries, which for the most part are small, and for the most part, also, enter the main valley either by a waterfall, or by a series of rapids running through steep-sided gorges. Such a condition is unusual, the tributaries of a stream as a general rule entering at even grade, as it is called—that is, there is no marked discontinuity of level between the side streams and the main

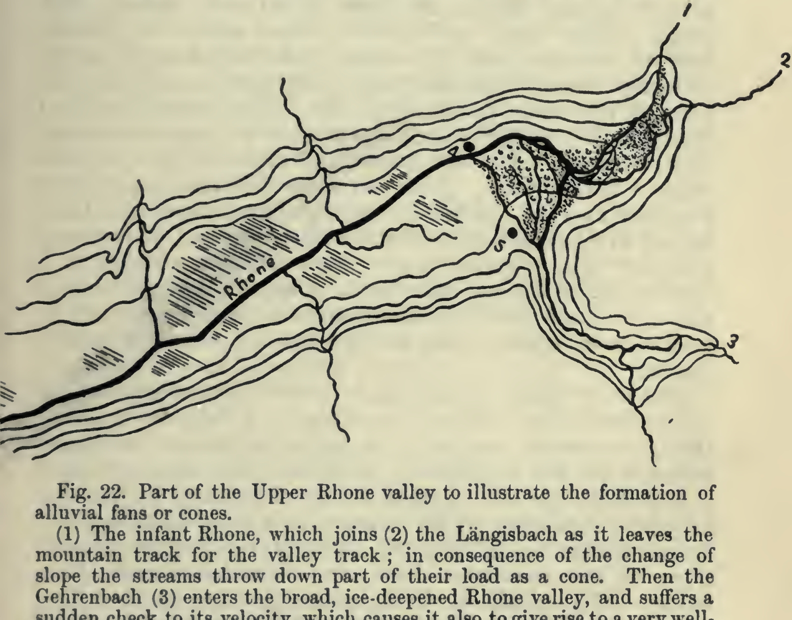

Fig. 22. Part of the Upper Rhone valley to illustrate the formation of alluvial fans or cones.

(1) The infant Rhone, which joins (2) the Längisbach as it leaves the mountain track for the valley track ; in consequence of the change of slope the streams throw down part of their load as a cone. Then the Gehrenbach (3) enters the broad, ice-deepened Rhone valley, and suffers a sudden check to its velocity, which causes it also to give rise to a very well-marked fan. The presence of this fan thrusts the main stream over to the right bank of the valley, whence it rebounds to strike against the left bank, as is shown in the lower part of the map. Note how the Gehrenbach splits up and forms streamlets through its fan, as in the case of delta formation, and from the same cause. (4) The village of Oberwald, (5) that of Unterwasser. (From the Swiss 1 : 50,000 map, contour lines at 30 metres or nearly 100 feet.)

streams. It is believed by many geographers that the Rhone valley in this region has been *over-deepened* by ice. This is a point to which we shall return later; the immediately interesting matter is that the water in the side

streams at the moment when it enters is flowing more rapidly than is the water of the main stream. The tributary water, therefore, receives a check at the moment of entrance. Now the amount of rock waste which a stream can carry is directly proportionate to its velocity, and therefore, with the check to the velocity of the side streams as they enter the valley, there is a tendency for them to throw down their waste. The heavier stones are dropped first, the lighter are carried further out on the floor of the main valley. The result is that where each lateral stream enters, an alluvial cone or fan is formed, the narrow part being directed up the tributary stream, and the wider part spread out upon the floor of the main valley (Fig. 22). The broad U-shaped Rhone valley is particularly favourable to the development of such cones, which are beautifully shown on the contour map of Switzerland. Even on a smaller scale map their presence may be realised by noting the swing of the main stream to right and left as the tributaries enter. A powerful tributary lays down so large a cone that the main river is forced over to the opposite bank, whence it swings back to the near bank once the obstruction is passed, only to be pushed over again to the further bank if a new tributary enters.

One other point is important. With rare exceptions, of which the Drance (already mentioned) is the most notable, the tributaries of the Rhone in its upper reaches are small rivers, with few tributaries, which have an almost straight course down the left or right wall of the valley, as the case may be. Not a few of the streams, it is true, unite together in pairs, but as a rule the streams follow the general slope of the mountain chain, and have no lateral tributaries. The result is that communication between one valley and the next is often somewhat difficult. In many cases only a very rough tract connects such valleys, and all but very agile persons must come down to the main valley in order to reach an adjacent tributary valley. We shall see later that this means that most of the tributaries of the Rhone in this region are of recent origin, it being characteristic of young rivers that a number of small parallel streams occur, in place of large, branching trunks. As numbers of such small streams tumble over the steep sides of the Rhone valley, and as each is cutting back the rocky wall at its entrance, and also laying down alluvium on the floor

of the main valley, we see that the tributaries tend both to raise the floor of that valley and at the same time to widen it. The widening process is assisted by weathering.

The cones laid down by the tributaries are of considerable human importance, for, with few exceptions, the villages of the main valley are placed upon them. The villagers thus gain dry situations for their houses, for they are raised above the swampy valley floor, and, as we shall see later, they escape also the winter chill which hangs over the valley. We may note also that the sloping regions formed by the alluvial cones or fans are often better suited for cultivation than the valley floor, for their coarser material and the slope make for more efficient drainage. The main valley is in many places marshy, and, despite the elaborate control works established in many parts of it, is very liable to flooding. Such flood water, as it evaporates or drains off, leaves behind a fine deposit of silt or mud. This in the long run is useful, for it increases the amount of soil; but if it occurs while the crops are growing it may completely destroy the prospect of a harvest for that particular season.

The slope of the valley from Oberwald to Martigny is relatively gentle, but where the river begins once again to erode in place of depositing, in order to cut its way through the mountains at the elbow of the Rhone, the slope increases. Such interruptions of slope are common throughout the course of this river, and show that, as a whole, it is relatively young. As we shall see, also, all parts of its course are not of the same age. Theoretically, the profile of a river should be an even curve, with a steadily diminishing slope from source to mouth. Only rarely, however, is this ideal condition attained.

The next point of interest is that the portion of the valley beyond the elbow is practically continuous with the course of the Drance. Further, if we suppose Lake Geneva not to be present, and it is certainly of recent origin, then the combined valley of the transverse Rhone and the Drance runs in the same direction as the small stream called the Broye, which lies to the north of Lake Geneva and drains into the Rhine system. Two conclusions may be deduced from these facts. First, the Rhone between Martigny and Lake Geneva is taking advantage of a valley which was originally excavated by the Drance, which is apparently an older stream than the Rhone. The Rhone is therefore said

to have *captured* the valley of the Drance. Second, prior to the formation of the depression in which Lake Geneva lies, the Rhone and the Drance both drained into the Rhine. Phenomena of this kind are very common in connection with the development of rivers, and we must give a little space to the discussion of them.

The diagram (Fig. 23) will help to make the matter clear. When a land surface begins to rise above sea-level, the water which falls upon it will drain off in the direction of the slope. Such streams are called *consequent*, because they are a necessary consequence of the slope. In I in the diagram two such rivers, *a* and *b*, are indicated. But, as we have already explained, though folded mountains owe their origin in broad outline to tectonic causes—*e.g.* to

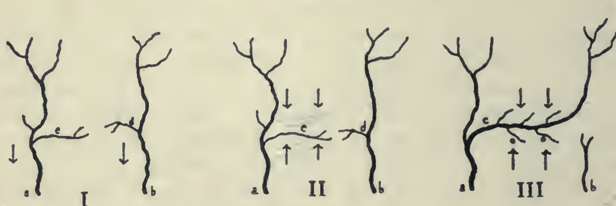

Fig. 23. Diagram illustrating river capture, and the differences between consequent (*a* and *b*), subsequent (*c* and *d*) and obsequent (*o*) streams.

earth movements—yet the details are produced entirely by erosion. The rivers flowing off the rising mountain slope soon begin to erode valleys for themselves, and as they do this they find inequalities in the hardness of the rocks. Also, while the folds within the mountains are at first deeply buried beneath superincumbent layers of rock, as denudation goes on they are gradually uncovered, and the varying arrangement of the beds, no less than their varying hardness, affects the power of the streams to erode. As the main trunks erode deeper and deeper, they develop lateral tributaries, which are longitudinal in relation to the mountain range, and are shown in I and II. We note also that the river *a*, which is running over softer beds, has greater erosive power than *b*. It tends, therefore, to lengthen its tributaries, and the lie of the rocks is such that one of the longitudinal tributaries has great powers of erosion. It pushes out towards the trunk *b*, and ulti-

mately succeeds in tapping one of the longitudinal tributaries of the latter river, and so in drawing off all its head waters, or in *beheading* it. This is called *capture*, *a* being said to have captured *b*; the sharp curve at the point where this has occurred forms the *elbow of capture*. As a result

Fig. 24. Synclinal and anticlinal valleys in the Jura.
The Doubs and the Dessoubre run at first northwards in synclinal valleys, but where the chain bends eastward the Doubs finds its way through it by an anticline thus forming a cluse, and then runs in the same synclinal valley as the Dessoubre, but in the reverse direction. The united stream again breaks through the chain transversely at the cluse of Pont de Roide, marked I on diagram, and finally runs south-west in another synclinal valley. The lines indicate the direction of the mountain ridges. (In part after de Lapparent.)

of the capture the longitudinal tributary (*c*) becomes a powerful stream, capable of carving out a deep valley. Meantime *b*, which has been beheaded, becomes an insignificant stream. As *c* carves out its broad and deep longitudinal valley, new tributaries begin to form on the sides of this valley, and it will be noted that some of these actually run in the reverse direction to the original streams. The longitudinal stream is called subsequent, because its origin is later in time than the original consequent stream, and the new transverse tributaries are called obsequent streams.

Longitudinal valleys of this kind are due to one of two causes. They may be due to the cropping up at the surface of a soft bed. Such valleys are called monoclinal, because the beds forming their floor are not curved as in anticlines

and synclines. In other cases such longitudinal valleys run along synclines—that is, along the hollows between the folds. The Rhone valley down to Martigny seems to run in such a hollow, and therefore to be at least in part a synclinal longitudinal valley.

Such longitudinal synclinal valleys are not uncommon in the Jura, and an example is shown in Fig. 24. The diagrammatic cross-sections of the great valley of Grésivaudan, in which the Isère runs (see Fig. 25), illustrates, on the other hand, the monoclinal type, the actual cause of the valley here being the junction of relatively soft sedimentary rocks with hard crystalline schists.

Fig. 25. Lateral shift of valley in the Upper Grésivaudan.
I. The Arly valley above Albertville. II. The Isère below Albertville (*cf.* Fig. 28). (1) Dogger and Lias beds, consisting of soft clays and sandstones. (2) Triassic sandstones, etc. (3) Hard crystalline rocks. In I the arrow points to the river, which lies in a valley at the junction of the soft and hard rocks. In II the fact that the soft rocks are much more easily eroded has resulted in the migration of the valley to the left. (After Lugeon.)

A comparison between the diagram (Fig. 23) and the map (Fig. 21) of the upper portion of the Rhone will show that from its source to Oberwald the Rhone is a consequent stream, from Oberwald to Martigny it is subsequent, receiving obsequent streams from the sides of the valley, while below Martigny it runs in the consequent valley of the Drance. When the Lake of Geneva was formed, apparently partly by earth movements, and partly as the result of the action of ice, it drowned the lower part of that valley, and so separated for ever the waters of the Rhone from those of the Rhine.

The transverse portion of the valley, between Martigny and St. Maurice, merits further discussion. The Drance obviously originally cut its way through a mountain barrier which obstructed its path. The Rhone below Lake Geneva, as we shall see, does the same thing, and throughout the Jura Mts. there are numerous instances of streams which have thus sawn their way through mountains (Fig. 24). In

some cases these streams existed before the mountains were formed, and as they rose slowly the stream was able to cut down its valley through the obstruction. But in the general case there is a remarkable correspondence between the structural form of the ground and the position of the transverse valley. In the Jura, as we have already pointed out (see Fig. 14, p. 41), the folding is exceedingly simple, and, as a general rule, the anticlines form hills and the synclines valleys. But the long anticlinal folds show at intervals depressions of the surface ridges, or saddles. These depressed regions may afford a direct passage to a stream, or they may be attacked by tributary streams, which, aided by the formation of the rocks, eat them out from either side. When the fold is in this way cut through, capture may take place, and the combined streams flow through a narrow gorge which cuts across the chain. Such narrow gorges are called *cluses*, and are exceedingly common in the Jura. They are to be regarded as the beginning of the processes by which the hills are made low, and a folded mountain range is worn down to a peneplain or upland. The diagram (Fig. 24) shows two examples of cluses.

When Lake Geneva was originally formed it was a much larger lake than at present, and extended up to St. Maurice. The Rhone, which enters it a turbid stream, leaves it with crystal clear waters at the town of Geneva, having deposited its load of silt and mud as a long alluvial fan, which has filled up the lake from St. Maurice to Villeneuve, and is still creeping out into the lake. The fan has indeed grown considerably since Roman times. Such a process of filling up of lakes goes on universally, so that all lakes on the course of streams have but a limited existence in time. In the Alps, however, the process of filling up goes on with special activity, owing to the fine glacial mud which so many of the streams hold in suspension.

If a little glacial water is taken in a tumbler, a fine powder begins to settle at the bottom almost at once, as the water, previously in motion, comes to rest in the glass. The check to the movement of the water, experienced as it enters the lake, has the same effect on a large scale, the lake thus acting as a temporary base-level. The filter-bed effect of Lake Geneva is shown with diagrammatic clearness at the junction of the Rhone and Arve below the town of Geneva. The Rhone has been filtered in the lake, the Arve carries its

load of mud straight from the glaciers of Chamonix to the plain, and for a short time the turbid Arve and clear Rhone flow side by side without mixing, this being the famous "jonction," which is one of the sights of Geneva.

Another very interesting effect of the lake may be realised by taking a bath first in the Rhone and then in the Arve at Geneva. The Arve, in the hottest weather, is icy cold, having been warmed very little during its journey from the glaciers of its origin to the junction. The Rhone, on the other hand, is much warmer, having lost in the lake the icy chill which it had when it entered it at Villeneuve. It might be supposed, then, that the Rhone was continually chilling the lake, but, curiously enough, this does not occur. Lake Geneva, like the other large lakes of the Alps, is deep, and the bathymetrical curve shows some curious relations. The deepest portion, which slightly exceeds 1,000 feet, lies between Lausanne and Evian, and from this region the lake gradually shallows towards Geneva, while the alluvial deposits cause it also to shallow towards Villeneuve. It is characteristic of lakes which lie in basins recently occupied by glaciers that the deepest part lies towards the anterior end, where the excavating power of the ice was presumably greatest. When the cold river water enters, owing to its greater density, it falls through the warmer, clear water of the lake in a kind of subaqueous waterfall, which may be imitated by pouring a heavy liquid into a glass containing a light one. Now, cold as the river water is, it is not so cold as that which lies in the greatest depths of the lake. This water is displaced by heavy river water, which thus warms the bottom of the lake. The overflow which escapes at the town of Geneva is the warm surface water, heated by the sun.

THE MIDDLE RHONE (Fig. 26).—After its junction with the Arve in the suburbs of the town of Geneva, shortly after leaving the lake, the Rhone finds its course blocked by the Jura (Fig. 3). The course of the river through this mountain system is complicated and demands careful consideration. No less than three times has it to cut transverse gorges through the mountains in order to overcome the obstacle which they offer to its course.

Of these gorges the first lies not far from the town of Geneva, where the river cuts through between the Grand Credo and the mountain of Vuache, forming the gorge of

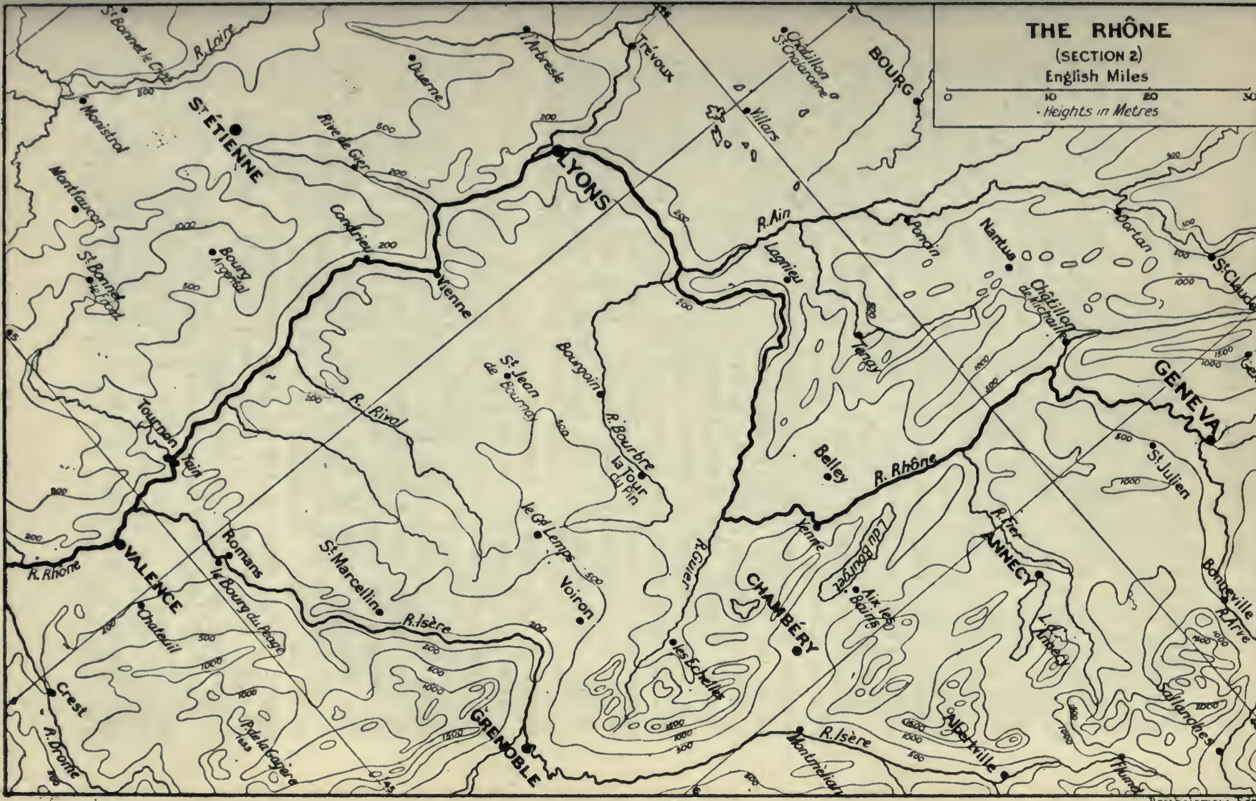

Fig. 26. The Middle Rhone.

the Fort de l'Ecluse, which allows for the passage of road and railway as well as of river. The steep-sided gorge or canyon is continued to Bellegarde, where the Rhone receives the Valserine from the north. Here it takes a sharp turn to the south, the elbow of capture showing clearly that it is taking advantage of what was once the valley of the former river. Near Bellegarde occurs the famous Perte du Rhône, now largely destroyed, and both the main river and the Valserine offer beautiful examples of the way in which running water erodes rocks. Of special interest are the pot-holes on the Valserine, where they are specially remarkable at the Pont des Oules, *oules* being patois for pot-hole.

The causation of pot-holes is interesting, and examples on a small scale may be found in almost every stream which is cutting through solid rock. River water, as we have seen, carries with it stones as well as fine débris, being able to move the former only when it is in rapid motion. As it swirls and eddies round the obstructing rocks, it rotates its load of stones, and these, necessarily hard, or they would not have persisted as stones, hollow out the rock beneath, so that deep holes are formed, at the bottoms of which the stones which acted as the graving tools may be seen lying. If two pot-holes form near together, then the breaking down of the wall between them may form a ravine into which the main stream flows, such broken pot-holes being common sights at the sides of streams.

Again, in limestone rocks a joint may be greatly enlarged by water, and ultimately serve as an entrance for a considerable portion of the stream. This carries its load of débris down with it, and if it encounters a softer bed below it may hollow out a large channel below the narrow cleft into which the water first sank. In this fashion, apparently, the disappearance of the Rhone (Perte du Rhône) was brought about, the narrowed stream flowing between rocky walls far below, concealed by a projecting cornice of rock above. The blowing up of this overhanging cornice has brought the river into sight, and largely destroyed an interesting geographical phenomenon.

Returning to the Rhone we may note that from Bellegarde past Culoz to Yenne the river runs due south in a longitudinal valley, lying between parallel chains of the Jura, and receiving as notable left-bank tributaries the Usses and Fier, the latter draining the lake of Annecy. In the lower

part of this region it runs almost parallel with the lake of Bourget, with which it is connected by a canalised stream of uncertain flow. This normally flows into the Rhone, but when the latter is in flood the lake serves as a reservoir for the flood water, so that the flow is reversed. Obviously, also, the level land below the entrance of the Fier and the marshy stretch to the north of Belley, called the marsh of Lavours, have both once been part of the lake. The Rhone, then, once entered an enlarged lake of Bourget transversely. Its delta filled up the portion of the lake stretching from the Fier to the northern extremity of the present lake, and, assisted by its tributary the Seran, it converted the western arm of the lake into a marsh. We have thus here another example of the tendency which rivers show to fill up lakes on their course. The smaller and shallower the lake the more rapid is the filling-up process.

At Yenne the river suddenly changes its southerly direction for a westerly one, and cuts through a second chain of the Jura. It then rounds a projecting spur of another chain, and turns to the north-east, to form a third and last transverse valley near Sualt-Brenaz, thus cutting through the last mountain which separates it from the broad trough of the Lower Rhone valley. On emerging on the plain it is pushed southward by the fan of the Ain, and then, after meandering over a plain strewn with glacial débris, it joins the Saône at Lyons.

THE LOWER RHONE.—From Lyons to the sea, as the map on p. 40 shows, a deep depression, once occupied by the sea, runs southward to the Mediterranean. This depression was caused by the resistance which the Central Massif of France offered to the folding which went on in the Alps to the east of it. The Central Plateau is composed of very hard rocks, resistant to folding, and here, as elsewhere (*cf.* p. 43), their resistance expressed itself in the form of faulting, and the consequent formation of a parallel-sided depression.

In regard to this part of the Rhone's course we need emphasise two points only. These are the great tributaries which the river receives, especially the Isère, Drome and Durance, and the large delta which forms where it enters the relatively still Mediterranean. As factors in the formation of the latter, we have to consider not only the absence of strong tides which might sweep away delta deposits as

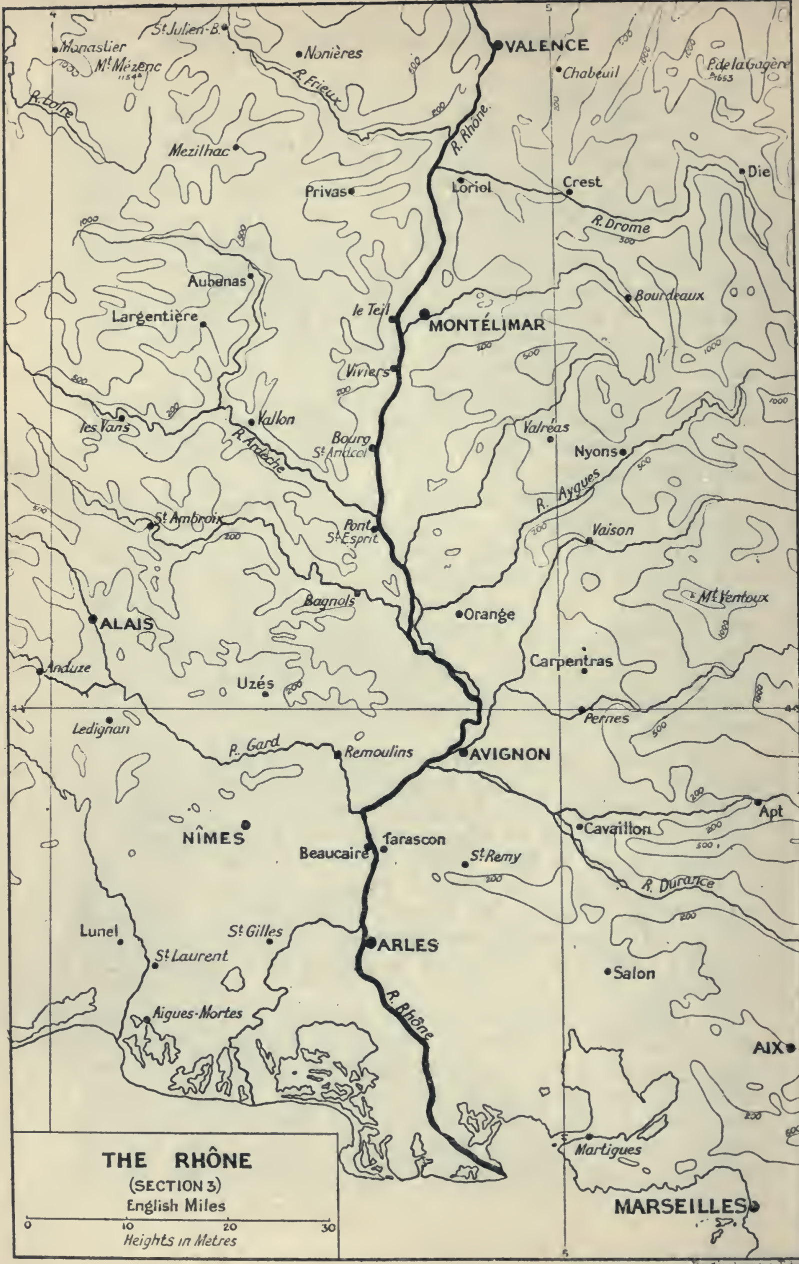

Fig. 27. The Lower Rhone.

they form, but also the enormous amount of glacial waste which lies over the plains near the lower Rhone, whose constituents are carried down to the sea by the rapid river. While the plain of the Camargue is the work of the Rhone,

Fig. 28. Sketch-map showing the upper end of the valley of Grésivaudan and the Lake of Annecy. The walls of the valley are indicated by shading. (1) The ill-defined watershed between the streams Eau-Morte and Chaise. (2) A dotted line indicating the position of a dry valley occupied by the Doron at the time when it flowed into the Chaise and so into the lake. Scale 7½ miles to an inch.

the Crau is believed to be that of the Durance, which once flowed past Salon to enter the Mediterranean directly instead of uniting to the Rhone.

THE UPPER ISÈRE REGION.—Before leaving the Rhone, however, we must turn back to consider some interesting points in regard to its tributaries, especially the mighty Isère.

As the sketch-map (Fig. 29) shows, the two lakes of Annecy and Bourget lie almost parallel to one another, and neither sends any important tributary to the Rhone. This is the more remarkable because to the south-east of them lies the Isère with its many tributaries, which in place of taking advantage of the depressions in which the lakes lie, travels a long distance southwards before it turns west to mingle its waters with those of the Rhone. Detailed examination of the conditions only increases the apparent anomaly.

The sketch-map (Fig. 28) shows the uppermost part of the great valley of Grésivaudan, and the region between its head and the lower end of the lake of Annecy. It will be seen that there is a sharp "elbow" between the upper valley of the Isère and that part of the stream which runs in the broad valley of Grésivaudan. Also the valley between Albertville and the upper end of the lake of Annecy has a very ill-defined divide, and the stream which runs into the lake, the Eau-Morte, is, as the name suggests, a sluggish stream. Close examination of the country makes it clear that the upper Isère once flowed into the lake, as did also the Arly and the Doron. But the present valley of Grésivaudan is excavated in relatively soft rock (*cf.* Fig. 25), and by the deepening of this valley the present Isère was able to capture first the stream which now forms its own head waters, and then the Doron and the Arly, thus diverting their waters from the lake of Annecy into the great longitudinal valley. The Doron shows very clearly the elbow of capture, and there is indicated on the sketch-map by a dotted line the position of a dry valley which once carried its waters *via* the Chaise into the lake.

On account of the diversion of the water which once flowed through it, the transverse valley between Albertville and the lake is now left almost dry, the insignificant streams which now occupy it bearing no relation to its size. Such valleys are called by French geographers "dead valleys," and by English ones "dry valleys," the latter being a less appropriate name, for some water may continue to flow through them.

In Fig. 29 it will be seen that a more imposing example of the same type of valley is found near Chambéry. This valley, through which the railway which pierces the Alps at the Mont Cenis tunnel runs, now carries no stream, though obviously this also is due to the development of the

great longitudinal valley of Grésivaudan, for once part of the waters of what is now the Isère passed through the Chambéry valley and the lake of Bourget direct to the Rhone. The figure also shows that the three rivers, the Upper Isère, the Arc and the insignificant Breda are nearly parallel consequent rivers, which have been captured by the large

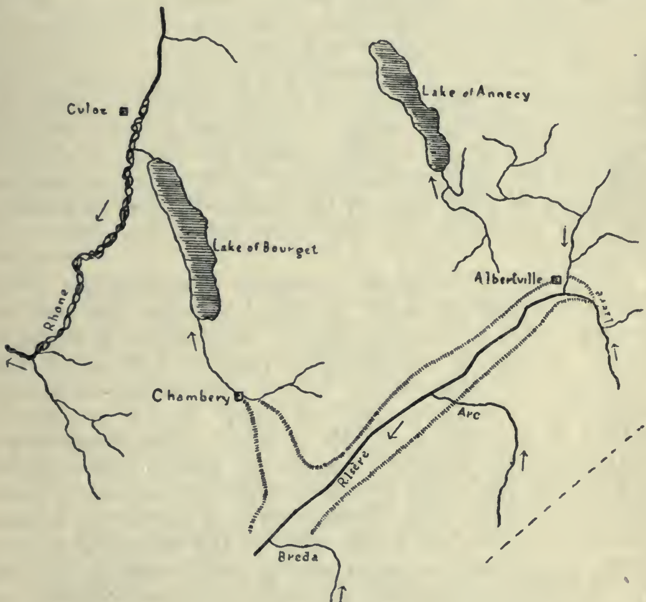

Fig. 29. Sketch-map showing part of the course of the Rhone, the lakes of Annecy and Bourget and the valley of Grésivaudan.

The dotted line to the right shows the position of the mountains from which the streams drain. Scale about 12 miles to an inch.

subsequent river which now forms the Isère (*cf.* Fig. 23). The dry transverse valleys which lead up to the southern ends of the two lakes mark the position of their former courses. The relation of the obsequent streams to the original consequent streams may be realised by noting that the Eau-Morte in Fig. 28 is the remains of a consequent stream, while the Chaise, which flows in the reverse direction, is an obsequent.

Effect of Streams on Upland Regions.—Such examples might be multiplied almost indefinitely, but those given, in combination with the previous description of the transverse portion of the Upper Rhone valley, serve to show that in a recently elevated mountain region river courses tend to consist of a combination of transverse and longitudinal valleys. Obviously the two are closely related. As we have just seen in the case of the Isère, the abandonment of a transverse valley by a stream of water is associated with an increase in length of a longitudinal valley, while conversely the development of a new transverse valley may shorten a previously existing longitudinal one. The net result is thus to cut up the country into a series of blocks separated by valleys. Each new valley adds to the area which can be acted upon by the ordinary agents of weathering, and increases the area over which streamlets may develop.

The object of the above somewhat detailed study of the Rhone has been to show by actual example the very important part which rivers play in the erosion of mountain tracts. It may be well to repeat that, in their origin, both transverse and longitudinal valleys may be due to tectonic causes, for the former are the result of the presence of saddles on the anticlinal folds, and the latter, sometimes at least, mark the position of synclinal folds. But while the first flow of the water is thus partially determined by structure, the ultimate form of the valleys is due to the unequal resistance which the rocks offer to the forces of erosion. Thus the longer the period during which erosion has gone on, the less obvious the connection between valleys and mountain structure. In the long run the synclines, which often form valleys in the Alps and Jura, become hills, because they yield less rapidly than the anticlines to the forces of erosion, and a so-called inversion of the relief is thus produced.

In the chapter on mountains we stated that it was the forces of erosion which wore down lofty folded mountains to the condition of uplands or peneplains. This discussion of the Rhone system is intended to indicate the exact way in which the process takes place.

But we have also to note that it is not only as folded mountains that new lands are raised above the surface. A folded area may, as the result of age-long denudation, be

worn down to a level, and be subsequently raised by slight earth movements to such a level that a new cycle of erosion commences. Beneath the layers of alluvium which were deposited on this area as it sank we have a grained surface, the graining being due to the way in which the forces of erosion have planed off the tops of the folds, so that if we travel, *e. g.* from the interior to the sea, we cross different kinds of rocks in succession. Graining may also be due to the way in which beds were deposited in shallow water round the margin of a rising land mass. As the land rises from the sea it shows a slight tilt, sufficient to allow for the establishment of consequent rivers. As these develop, and throw out tributaries, they soon wear away the surface deposits, and expose the underlying rocks, which respond unequally to the denuding forces. The result is that, largely on account of the action of the subsequent longitudinal tributaries, the hard beds come to stand out as escarpments, while the softer ones form wide lowlands. Through the escarpments of the harder rocks the rivers cut gorges, because the river existed before the hard rock was so dissected out as to form an escarpment. Such gorges, called water-gaps, are common in England, and may be puzzling if their origin is not understood. When on account of capture the river which formerly flowed through such a gorge has disappeared, the notch persists and is called a wind-gap. The English plain has been much dissected by running water, and wind-gaps and water-gaps are frequent, as is also the emergence of the harder bands of rock as escarpments.

The Work of Rivers in General.—If we sum up what we have learnt from this study of the Rhone, we may note first that the different parts of its valley are not all of the same age. The Alps, we may repeat, are of recent origin, and the Rhone and its manifold tributaries show the strange changes and metamorphoses which the drainage system of a newly elevated area undergoes. From the first torrents which run off the rising land, an elaborate and complex river system is evolved, a process which involves many captures and the beheading of many tributary streams.

In the case of the Rhone the adjustment of the rivers to the surface is not complete, and captures are still going on. Further, the river shows well-marked rapid reaches and slow reaches, and is still eating its way through deep gorges. A

profile of its valley would bring out this fact, by showing inequalities of slope. We have seen also that though the Rhone has filled up that part of the lake of Bourget which crossed its course, it is still far from having filled up the lake of Geneva.

Such a river is said to be young. If space had permitted we might have contrasted with the Rhone such a river as the Loire. Here the profile is smooth, and the steepness of the slope diminishes steadily from the source to the mouth. Such a river is an old river, one which has flowed along its present course for a prolonged period, and has long ago reached a position of equilibrium. On the course of such rivers lakes tend to be absent, waterfalls have disappeared, inequalities have been smoothed out, and all the

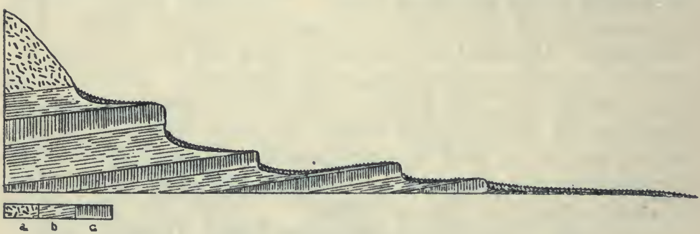

Fig. 30. Diagram to illustrate the alternation of steep and level reaches on the course of a river. The slope is enormously exaggerated.

(*a*) The mountain region. (*b*) Regions of soft rocks, easily eroded; deposition tends to take place here while the river is engaged in cutting down through (*c*), beds of hard rocks. If such hard beds alternate with softer ones, then we shall have an alternation of waterfalls or gorges and level stretches, where deposition takes place. The dots represent alluvial deposits, and the diagram shows that exposed rock surfaces are only to be expected in the upper reaches; further down the rocks are completely covered by transported material.

lower portions of the river flow among alluvial flats of its own making.

More in detail we may note that young rivers tend to show a frequent alternation of lake or valley flat and gorge or waterfall (see Fig. 30). The gorge or waterfall means that the water has reached some specially hard layer of rock. As a consequence the rapidity of flow is checked above the obstacle, and the stream tends to widen out there. A lake may be formed, to be later filled up by the alluvial fan of the stream. In any case in this region the check to velocity

causes the stream to throw down its débris. But sooner or later the obstacle is cut through, and the waterfall is replaced by rapids; when this happens the velocity is no longer checked, and the stream will tend to wash away the alluvial flat it previously formed. This means that the waste is being carried nearer to the sea, and a repetition of the process at lower and lower levels causes the deposition of the greater part of the alluvium in the lower reaches, which thus have their slope flattened out.

Again, the young stream tends to cut down the rocks of its bed into a V-shape, but in an old river, when the atmospheric agents have had time to act upon the exposed sides, there is a tendency for the valley to broaden out at the base, and to become wider. As the slope is diminished with the laying down of alluvium in the lower reaches, the rapidity of flow diminishes, and the river deposits its waste in the slack water at its margins. The floor of the valley may thus be so raised that except at flood-time the river cannot cover the whole of it. At flood-time the waters spread over these alluvial flats, and raise their surface by deposition. Over such flats the river meanders freely, turning now to right and now to left in its search for the easiest course. Sometimes two meanders approach one another so closely that the bend is cut off, leaving what is called an ox-bow lake (Fig. 31), such ox-bow lakes being common on the wide flood-plain of the Mississippi.

When from any cause a river flowing through a flood-plain of its own making begins to scour out its bed, then it may be unable to rise, even in flood-time, to the level of its own old plain, and fragments of this are left as river terraces or benches, above the level of the existing valley.

As a general rule rivers tend to erode both banks equally. Exceptions may arise where the two banks are of different hardness, or where the dip of the rocks is such as to make it easier for one bank to be undermined than the other. But in addition to these cases constant distinctions between the two banks are noticeable in south-to-north flowing rivers. On a small scale this occurs in the Pyrenees, where the right or eastern bank is regularly more attacked than the left or western bank. This is ascribed largely to the prevalence of westerly winds which constantly drive the water against the eastern bank.

The phenomenon is more strongly marked in the long rivers of northern Asia which drain into the Arctic Ocean.

Fig. 31. Stages in the development of ox-bow lakes.

In A, the Osage River is just about to abandon a broad meander for the shorter course across its ends. Silting-up will then take place at the ends of the curve, which will thus be converted into a curved pond such as that shown in B. A pond which has been produced in the same fashion is shown further down the course of this stream, whose direction is shown by the arrow. (From the U.S.A. topographic map, Butler, Mo. sheet.)

In B a completely formed ox-bow is shown on the course of the White River, also an elongated pond produced from another cut-off meander. (Part of Princeton, Ind.-ILL. sheet.)

Here the right bank is regularly cut back as a cliff, while the left bank is low and fringed by alluvial deposits. This

is usually cited as a particular case of Ferrel's law, according to which, "if a body moves in any direction on the earth's surface, there is a deflecting force arising from the earth's rotation which tends to deflect it to the right in the northern hemisphere, and to the left in the southern hemisphere."

The reason for this is obvious. Every particle on the earth's surface is rotating from west to east. But particles near the equator, which have a longer distance to travel each twenty-four hours, must necessarily have a greater velocity than particles near the pole which in the same time travel through a shorter distance. Therefore any moving body, coming from south to north, will tend to be deflected towards the east or right hand. In the case of rivers the water will tend to be deflected against the right bank.

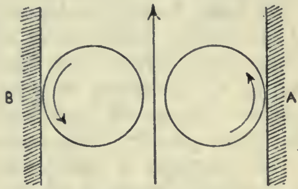

Fig. 32. Effect of eddies on the banks of a stream. The river is supposed to be flowing in the direction of the arrow, and it will be noticed that while at A the eddy reinforces the action of the current, at B it diminishes it; thus the bank at A will tend to wear away faster than that at B. (After de Lapparent.)

In point of fact, however, this deflecting force does not seem great enough to explain the observed difference in the amount of erosion of the two banks, and it has been suggested that the effect is really one of eddies. It seems to be the whirl of the water in an eddy which has the sapping effect on the banks, and such eddies may be direct, *i. e.* the movement of the water is in the same direction as that of the hands of a watch, or inverse, *i. e.* in the opposite direction. Apparently the effect of the earth's rotation expresses itself in the production of inverse eddies against the right bank, and direct ones against the left bank. At the right side, therefore, the effect of the eddy is to increase the velocity of the movement of translation of the water, while in the direct eddy of the left bank the effect is to diminish this velocity—hence the greater effect on the right bank (see Fig. 32).

The Cycle of Erosion.—We have described above in detail a river which in parts of its course at least is a young river, and we have pointed out some of the respects in which

such a river differs from one which has been acting for a prolonged period upon the surface. Theoretically, every river should during its existence pass through the whole Cycle of Erosion, from the early period when it has a markedly irregular profile, interrupted by lakes and waterfalls, and when captures are constantly taking place, to the final period when its profile is smoothed out, its lower reaches are choked with alluvial deposits, and its power of carving up the land has largely diminished with the reduction of the slope. Such a river is said to have reached the condition of old age, and the country through which it runs has been largely reduced to the condition of a peneplain. Practically, however, it seems unusual for the whole of a long river system to reach maturity in this way. Quite often uplift occurs in some part of its course, renewing the erosive power of that region, and producing a new irregularity of profile. For example, the lower part of the Rhone runs through a valley which is very old, though it was somewhat modified at the time of the uplift of the Alps. This part of the river, therefore, is much older than the other parts, and such a condition often occurs. In general, though every river tends to wear the land through which it runs to the condition of a gently sloping plain, and thus tends to lose its own power of eroding, yet the constant occurrence of earth movements gives new power to the rivers, and prevents the condition of equilibrium from being reached.

Further, we must note that while theoretically any river should pass through the whole cycle from youth to old age, yet in practice the nature of the rocks over which it flows exercises a marked influence. Thus, while in hard rocks maturity is long delayed, in soft rocks the condition described as senile is early reached. Rivers running over soft impermeable beds, such as clay, cannot form gorges, for the walls of their valleys begin to slide so soon as a certain slope is reached. The result is that the valleys soon become wide, and the stream, which spreads out in the valley, is unable to excavate its bed deeply. In such regions the drainage may become uncertain, marshes and lakes being frequent, and the rivers meandering slowly over wide plains. Springs are absent, and flowing water is always muddy, owing to the presence of fine particles in suspension. In France, where considerable areas are covered with clay, striking examples

are common. Thus in the department of Ain we have the Pays de Dombes, a region strewn with lakes and marshes, and having very imperfect drainage. The district lies in the angle formed by the Rhone and the Saône, and is covered with glacial clay; hence the nature of the drainage. Similarly, on the Loire in the department of Loir et Cher and the neighbouring departments we find the district of the Sologne (see Fig. 33) covered in the same way with ponds

Fig. 33. A portion of the plateau of Sologne, to show the characteristic drainage system of a region floored with impermeable clay.

There is a virtual absence of relief, the streams being unable to form valleys, owing to the way in which the clay slips. The stagnation of the water is shown by the vast number of ponds and marshes, and is characteristic. Reduced from the 1 : 200,000 map.

and marshes. Such regions are little fitted for human occupation, the undrained land being infertile. In some instances, *e. g.* in the Sologne, afforestation with pines effects great improvement.

The same type of surface occurs, though less markedly, in the plain of the Woëvre in Lorraine, and is due to the fact that Liassic clay appears at the surface.

An interesting problem connected with the cycle of erosion is the question of the actual amount of denuding work rivers are doing as individuals or in combination. In the case of glacial streams, always loaded with fine particles in suspension, the calculation of the denuding force is a relatively simple matter, and many will recall an eloquent description by Ruskin of a simple experiment which he performed. In this case all that is necessary is to take a measured quantity of water from a glacial torrent, filter it, dry the deposit and weigh it. If a series of observations are then taken as to the mean discharge of the stream, it is a mere matter of arithmetic to make a rough calculation of the amount of waste the stream is carrying, and therefore of its denuding work. As, however, the water is also carrying away matter in solution, it is necessary to evaporate a measured amount to dryness, weigh the residue, and add the result to the amount carried in suspension.

With non-glacial rivers the matter is much more complicated, for, with some exceptions, such rivers only carry matter in suspension when they are in flood. Further, to the amount actually carried it is necessary to add the gravels, etc., rolled along the bottom. Here, also, allowance must be made for matter carried in solution.

The most elaborate series of observations of this kind which have been published date back to 1861, and were made on the Mississippi by Messrs. Humphreys and Abbott. Their net result was that this river is annually reducing the whole surface of its basin by ·002 of an inch per annum. It is believed that this river may be taken as generally representative of the rivers of the world, and on this basis a calculation has been made that if the present rivers continued to act at present rates the whole of the continents would be worn down to sea-level in 7,000,000 years. This calculation refers only to material carried in suspension, and allows nothing for that in solution. Such calculations are, perhaps, not of great scientific value, but those interested will find full details in Penck's *Morphologie der Erdoberfläche* or de Lapparent's *Traité de Géologie*.

Another possible method of estimating the extent to which rivers are wearing down the land is by calculating the growth of deltas, and in regard to this some interesting detailed observations have been made.

One point may be noted in conclusion. However uncertain the figures which all such calculations yield, they

emphasise at least the inequality of the load carried by the different rivers. Thus the Po and Ganges carry a large amount of matter in solution, the Danube and Nile much less. Both the former take their origin in recently elevated mountain chains of great height, and we have thus emphasised afresh, from a different point of view, the enormous amount of erosion which goes on in such mountain chains

CHAPTER VII

COASTAL TOPOGRAPHY AND THE WORK OF THE SEA

The Sea as a Denuding Agent.—Deposition in the Sea.—Coral Islands.—General Characters of Marine Deposits.—Types of Shorelines: (1) Coastal Plains; (2) Folded Shore-lines, Longitudinal and Transverse; Rias; Fiords; (3) Regions of Recent Fracture.—Coasts of the British Islands.

We have now considered the effect of the atmosphere and the other agents of sub-ærial denudation upon the surface, as well as the action of running water. There still remains as denuding agents the sea and ice, both with a more limited field of action than the agents just mentioned. Ice at the present day acts upon a very restricted part of the earth's surface, and the sea affects the land only at the junction zone between the two.

The Sea as a Denuding Agent.—If we consider first the sea as a denuding agent acting upon the shore, we must note that it owes its power largely to the action of tides and winds. In seas where tides are important, twice a day the waves travel up the beach, bearing a load of sand, pebbles and stones with them; and twice a day they retreat again, dragging their load back with them. When enforced by tempests the waves may act high above the normal high-tide mark, while the force of the tidal current makes itself felt 30–65 feet below the surface-level of the water. Other things being equal, then, it is obvious that shores off which a strong tidal current runs are more likely to be denuded by the sea than those which face enclosed seas where the tides are insignificant; exposed shores, also, will be more liable to attack than those sheltered from the prevalent winds. Again, the waves, like running water, owe much of their power to the weapons, in the shape of stones, etc., which they carry. In consequence, marine erosion is at its maximum on shores like the west coast of Europe, and at its minimum in seas like the Mediterranean, as is indicated by the frequency of deltas in the latter sea, and their absence off the exposed western coast of Europe.

The diagram (Fig. 34) shows how the waves acting upon a shore which had originally a considerable slope, cut out a cliff, and lay down in front of this a platform of erosion, built up of the waste of the land. Where the rocks forming the sea margin are uniform, the line of cliffs will be uniform also. Frequently, however, slight inequalities of hardness, etc., occur, resulting in the formation of pinnacles, stacks, reefs and islets, such as form conspicuous features off many rocky coasts. So conspicuous are these that we commonly find that the local patois of such regions contains words used to designate the particular form which occurs in the locality. Stack and skerry are examples of such words which have passed into geological nomenclature, and there are many others.

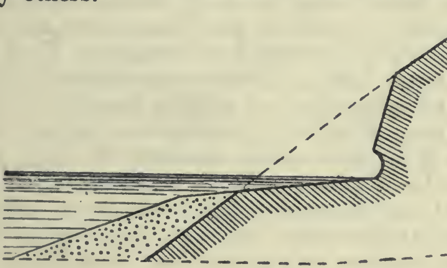

Fig. 34. Diagram to show the method of formation of a sea cliff. The dotted line marks the original outline of the coast. The effect of the waves is to cut this back and so form a cliff with a sloping beach at the base. The débris removed from the cliff tends to form a submarine bank, shown by the dotted area. (After de Lapparent.)

It is not uncommon to find that small islets have been formed in this way, by the separation of a specially hard region from the shore, but even large islands may also arise. Thus the Channel Islands closely resemble the adjacent peninsula of Cotentin, and have apparently been separated from them by marine erosion. When assisted by earth movements such separation of parts of an originally continuous coast-line may take place on the large scale. For example, right up the exposed part of the west of Europe, from Portugal to the north of Scotland, we have a mostly rocky coast-line, extensively broken up into peninsulas, and fringed with many rocky islands. Though there has certainly been fracture here, associated with the formation of

the North Atlantic, yet the sea has played a considerable part in this dissection of the shore. But in the general case, unless earth movements intervene, marine erosion has a limited horizontal extension.

Deposition in the Sea.—Not everywhere do the waves erode. Where the coast is low, and fringed by shallow water, the force of the waves may be spent before they reach the shore, and then deposition rather than erosion may occur. As in the case of rivers, indeed, the two tend to alternate continually with each other. Any check to the rapidity of movement of the tidal currents, such as are caused by promontories, bays, etc., causes the water to throw down some of its load. We have to remember that the load in this case is not only derived from the active work of erosion; the rivers also bring down in abundance land waste, which is sorted and rearranged by the waves. Where the coast has no marked promontories or bays, the débris may be laid down as a uniform bank along the shore, forming a kind of dyke. Sometimes a lagoon is formed behind this dyke, which may ultimately be filled up, partly by the growth of plants, and so form new land. Again, such littoral deposits may extend out from the shore to islands lying off the coast, and thus tie these to the mainland, converting them into peninsulas. The Bill of Portland in southern England has become a peninsula in this fashion, and Holy Island off the coast of Northumberland is in process of being tied to the mainland in the same way. In the Mediterranean the formation of spits of sand and gravel stretching out from the shore to islands, and thus uniting these to the mainland, is common. A very striking example is Monte Argentario off the western coast of Italy, a former island linked up to the mainland by no less than three such bands of débris. The Italian word *tombolo* (a cushion or lace pillow) is in Italy habitually applied to such conditions, and is sometimes used as a geographical term.

Where the winds are strong the débris may be piled up as sand-dunes (*cf.* p. 61). Sand-dunes occur off many parts of the British coast; *e. g.* off the coasts of Ayrshire, Northumberland, on the Wirral, etc.

Where deltas form in quiet waters at the mouths of rivers many types of islands and peninsulas arise, as the currents drift this way and that.

The examples already given of land-building in the sea

have been the result of mechanical forces only, but plants and animals may assist the process. For example, in tropical latitudes mangroves establish themselves on the swampy flats which fringe the coast-line in many places. As their roots ramify over the surface they form veritable traps for mud and sand, and thus help to raise the surface above sea-level.

Coral Islands.—More striking is the work done by corals and associated organisms in forming coral islands. Corals are organisms closely related to sea-anemones which possess the power of secreting lime from sea water. They grow only in warm water, temperatures below 68° F. being unsuitable, and, perhaps on account of the coldness of deep water, do not flourish at depths greater than about 90 feet, though they sometimes occur down to 150 feet. With the corals live a great number of other lime-secreting organisms, including calcareous seaweeds, sponges, and so forth. The hard parts of these animals form ultimately solid blocks of limestone, which constitute coral islands or reefs.

Three types of coral reefs can be distinguished: the fringing reef, where the deposits of limestone form a fringe round a coast-line; the barrier-reef, well exemplified off the eastern coast of Australia, where a channel of water of considerable depth lies between the reef and the coast; finally, atolls, which are more or less circular, are reefs which enclose an area of shallow water, the lagoon. It was first suggested by Darwin that these three represent three stages in one process, and this view has been generally, though not universally, accepted. Darwin believed that atolls and barrier-reefs show that subsidence is going on. The corals settle round a shore, in many cases round the margin of a volcanic islet, and there form a fringing reef. If the island is slowly subsiding, then free growth will only take place round the seaward margin where the corals can grow upward into the shallower water, the sinking island causing the formation of the channel between the reef and the shore. If the island subsides completely beneath the surface, then an atoll is left, whose lagoon marks the position of the vanished island.

It is, however, certain that in the actual formation of the coral reef erosion and deposition play a considerable part. Parts of the coral rock are torn off by the waves and piled up elsewhere. Waves and wind may likewise reduce the

rock to the condition of sand, which helps to build up reef above sea-level.

Coral islands, with their characteristic vegetation of cocoanut palms, grown from wave-brought nuts, their absence of indigenous mammals, their frequent abundance of fish, have given rise to human groups of great geographical interest, because of the close control which the natural conditions exercise upon the mode of life. The inhabitants are necessarily skilful navigators, for only such could reach the islands in the first place; they are frequently cannibals, on account of the paucity of flesh food, and show in several other respects the effects of the natural conditions. The plants and animals of the islands also are of great biological interest.

General Characters of Marine Deposits.—Though corals are confined to warm seas, it is not only in these that limestones of organic origin are forming at the present day. Many marine animals have the power of taking up lime from sea water and building it up into their own hard parts. Among these are most molluscs; sea-urchins and their allies; many sponges; some marine worms which build tubes of lime, and so forth. The hard parts of these animals may accumulate off shores, and there give rise ultimately to limestone. Limestones of such types are frequent among the rocks forming the earth's crust, and are sometimes crowded with fossils, suggesting that a common death overtook a great number of organisms at once. A possible cause for this is the pouring into a clear bay of a quantity of turbid water, as a result of floods, changes in drainage systems, and so forth, such muddy water being very fatal to many marine organisms.

Generally we may indicate as follows the kinds of deposits which are forming near the shores of seas at the present day. Between and just below tide-marks we have beds of shingle, gravel and sand, frequently alternating, and only rarely containing complete organisms, though often with fragments of their hard parts, and showing also traces of land animals, *e. g.* tracks, etc. These are the littoral deposits. The larger stones and pebbles can only be carried by the waves a relatively short distance, so that in passing from the shore we soon leave the coarse littoral deposits for the finer-grained infra-littoral deposits, where fine sand and mud predominate. As the wave action is less here, and the

beds remain permanently beneath water, complete organisms must be often embedded in the mud. We should thus expect such beds, if hardened into rock, to be loaded with fossils. Further from the shore, or in regions where from any cause there is but little land-derived waste and the water is consequently clear, as well as still, the hard parts of lime-secreting organisms will accumulate. In warm seas in such circumstances coral reefs form; in colder ones beds of shells, etc., may arise. The name of oceanic is sometimes applied to such deposits, because the influence of the land is minimal.

As suggested above, in the general case only fine land waste is carried far from the shore. If, therefore, we find on the floor of the sea large stones and rocks, we suspect that some special influence has been at work. In the Arctic to-day (and over a wide area during the Glacial Period), ice is responsible for the transportation of stones, etc., out to sea. Elsewhere the presence of stones on the sea bottom far from shore has been held to prove that the waves have destroyed a previously existing land surface.

These facts are of great interest, because they throw so much light upon the method of formation of many of the rocks which we see upon the surface of the land. Marine deposits of pebbles and coarse sand give rise to rocks like conglomerates and grits; fine sands are compacted into sandstones; mud forms shale or may be so altered as to give rise to slate; coral reefs or shell deposits form limestones, and so forth.

Further, if the rivers which open on a particular coast-line are bringing down an enormous load of waste, and the waves are depositing this along the beach, and adding to it by tearing off new fragments of rocks from the shore-line, we have the formation of a series of beds which, generally speaking, become finer and finer as we pass from the shore seawards. But if the amount of waste so laid down is very large, then there is reason to believe that the shore-line may slowly sink beneath the weight. Obviously, then, what was once the littoral zone becomes the infra-littoral zone of the new coast, and fresh beds will overlap the old. This process of the sinking of the shore-line, and of the consequent creep of marine deposits over what was once land, may go on for long ages, till ultimately a reverse movement takes place, and a great area of sea bottom, with its superincumbent load

of waste, now compacted into rock, is raised up to form new land. This seems to have happened frequently. For example, the gently sloping beds which fill the huge space between the Appalachian Mountains to the east and the mountain backbone to the west in North America, seem to have arisen in this way by deposition over a slowly sinking area. Just, then, as the rivers and the land suggest a ceaseless state of flux, so the shore tells the same tale. The waves beat upon the beach and cut its margin back. But the material so cut off is spread upon the floor of the sea, and is destined to be raised above the level of the sea to form new land. Everywhere water wears down the surface, but everywhere also it builds again the materials which form new lands.

Types of Shore-lines.—To this general account of the work of the sea as an eroding and depositing agent we must add a few words on the forms of coasts. These show great variation, and the form in any particular case is due to the combined effects of crustal movements and littoral erosion.

1. *Coastal Plains*.—Let us take first the case of a coastal plain, much dissected by streams, and then gradually submerged beneath the sea. The wide river valleys now become large bays, running far into the interior. The more elevated portions of the surface stand up as low islands, and the whole region, with its calm channels well fitted for navigation and offering suitable sites for harbours, is well adapted for human occupation. Sea-cliffs may alternate with sandy or shingly beaches, bays and gulfs with headlands and promontories. Such a young coastal plain is well seen on the eastern coast of the United States, *e. g.* off Maryland.

But no sooner has the movement ceased than the sea begins its work of modification. Littoral deposits link the islands to the mainland, fill up the mouths of bays and convert them into lakes or lagoons, while at the same time the rivers begin to silt up their estuaries. Thus the young coastal plain passes into an older type, well exemplified in the Baltic coast of Prussia and in the region of *étangs* in Languedoc, *étangs* being shallow, brackish or salt pools in process of silting up. Here navigation is rendered progressively more and more difficult, the havens tending to have their entrances closed up by littoral deposits.

A still further stage is represented on the coast of Holland and the adjacent coasts of Germany, no less than

in the Fen country of eastern England. Here the stagnating pools of the previous stage are silted up and form marshes, which can be often reclaimed for cultivation, though they are always liable to inundation by the sea. When this stage is reached the rivers, if the conditions are favourable, tend to form deltas, this marking a final stage in the encroachment of the land on the sea. Thus, off coast-lines of this type the sea tends to replace the original inequalities by a rounded margin.

Where the flat coastal plain has been previously moulded by ice instead of by water, some special conditions occur. Here the surface is strewn with morainic débris, aranged in mounds of peculiar shape (eskers and drumlins); deep hollows mark the position of old sub-glacial torrents, or indicate the track of the last tongues of ice; huge erratic blocks may also occur. When such a plain is submerged

Fig. 35. Part of the eastern shore of the Adriatic, to show the Dalmatian type of coast. Scale about 4 miles to an inch.
Note the characteristic longitudinal channels or "canals."

an extraordinarily irregular topography is produced. The coast is very much cut up. There are many islands and rocky islets, many lakes and branching inlets. Such a coast-line is well exemplified in Finland (see Fig. 42, p. 127) and southern Sweden, and also in part of Iceland and in Maine in the United States, and owes the peculiarity of form to the action of the ice.

2. *Folded Shore-lines.* (a) *Longitudinal.*—In sharp contrast with such regions of coastal plains are those shores where mountains arise from near the water's edge. In this case obviously one of two conditions may occur. The ridges which form the mountains may run parallel to the coast-line, or they may be at right angles to it, when it appears as if it had cut through the mountain range transversely.

The first condition is well illustrated off the coast of Dalmatia, whence the term Dalmatian sometimes applied to the type. The study of longitudinal and tranverse valleys in mountain regions in the previous chapter makes it easy to realise the kind of appearance which such a coast-line presents (see Fig. 35). The longitudinal valleys form long channels or canals, to whose seaward side lie elongated islands, which are ridges converted into islands by the flooding of transverse valleys. The sheltered channels have frequently ports on their inland shores.

2. *Folded Shore-lines.* (b) *Transverse.*—The other type is exemplified on the western coast of Asia Minor or, in the case of much older mountain regions, by the coasts of

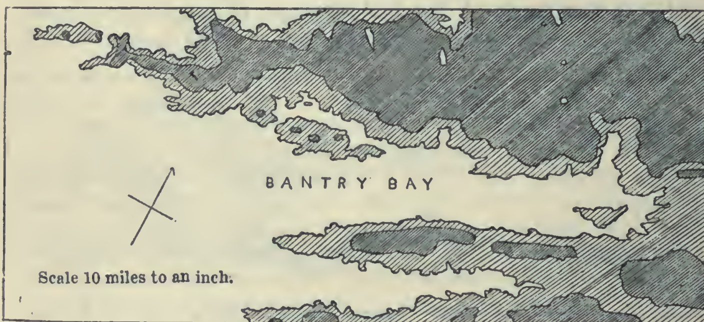

Fig. 36. Bantry Bay and Dunmanus Bay, Ireland, to show a typical ria coast. The dark shading shows land whose height exceeds 500 feet above sea level.

Brittany, south-western Ireland and South Wales. In this case the extremities of the mountain folds form promontories, the longitudinal valleys form bays (see Fig. 36). Where the sea is stormy, as in the two latter cases, the extremities of the promontories tend to be cut off as islets or ground down to the condition of reefs, while, on the other hand, the bays tend to be silted up. The coast is, therefore, frequently a very dangerous one, not offering safe harbours like the preceding.

Rias.—The type of shore-line just described—that found where a worn-down mountain region meets the sea transversely—often shows some special features of great interest. As we have already seen, such regions, which represent very

old land surfaces, often feel the repercussion of folding going on at a distance from them, and may thus come to occupy anew a higher position relatively to the surrounding lands, after they have been worn down to the condition of a peneplain. This leads to rejuvenescence of their river systems, and the streams begin to cut down narrow valleys, with almost perpendicular walls. If the region now undergo subsidence, these valleys are invaded by the sea, when they form what are called rias. Rias are bays or gulfs which run up into the land, often branching at their extremities, and receiving as separate rivers the streams which were once tributary to the main valley. The bottom deepens steadily on passing seawards, and the old valley walls form ridges bounding the bay. Very typical rias occur off the north-western coast of Spain, and form, *e.g.* in the bay of Vigo, ports of some importance on that inhospitable coast. The bays often contain islets which represent the most resistant portions of the rock which formed the surface of the peneplain. Similar inlets occur on the coasts of Brittany, south-west England, Wales, Ireland, and southern China (see Fig. 36).

Fiords.—In marked contrast with rias are fiords, which also occur on coasts where a worn-down upland meets the sea. Fiords show all the characters, to be described later, of glaciated valleys. They are overdeepened as compared with their tributary valleys, they have steep walls and broad U-shaped bases, and, as their most characteristic feature, we note that they do not deepen regularly when followed from the shore seawards. Frequently there is a shallow rocky bar near the mouth, comparable to the bar which stretches across some glaciated valleys, and the deepest part of the fiord, like the deepest part of such lakes as Geneva (*cf.* p. 78), corresponds to the region where the ice was thickest. Fiords may branch and interlace, and are of great importance in navigation. The term fiord is applied to such inlets in Norway (Fig. 37), and is now used generally. Fiords are also found on the coast of Greenland and on the western coast of Patagonia.

3. *Regions of Recent Fracture.*—Still another type of coast occurs in regions where local subsidence is going on actively, accompanied by volcanic disturbances. Here sections of the crust sink down, forming bays and inlets whose margins are bounded by fault scarps. The formation of volcanic cones and the throwing out of volcanic material

produce many local peculiarities. Of such coasts southern Italy and Greece and Japan present examples.

This brief account of coasts may serve to emphasise, from

Fig. 37. The Trondhiem Fiord, Norway.

Note the branching form. The figures are depths in fathoms, and show the presence of deep basins, separated from each other by shallower sills. Contrast the rias shown in Fig. 36.

another point of view, the relatively small importance of marine denudation. The waves smoothe off irregularities, fill up bays, and likewise cut off islands from promontories, only ultimately to wear the islands away; they do not, however, produce conspicuous land features, and these, when

they occur, are nearly always to be ascribed to the drowning of a dissected land surface.

Coasts of British Islands.—As the subject of coast-lines offers considerable difficulties, owing to the fact that the work of marine erosion is being continually modified by earth movements, and is influenced by the different nature of the rocks exposed at the margin, we may add to the above account a brief note on the chief kinds of shores which occur in the British Islands.

On the eastern and south-eastern coasts of England, from the mouth of the Tees to Lyme Regis, young rocks (of Secondary and Tertiary age) form the margin of the sea. All the eastern part of England is an elevated coastal plain, composed of rocks laid down on the sea bottom, and subsequently raised above the surface without any folding. Round the whole area mentioned, therefore, the sea-margin is formed by the edge of the English plain, and the varying nature of the coast-line is due to the fact that rocks of different characters are exposed. Where hard rocks like chalk form the margin, they tend to be cut up into cliffs and headlands, which resist the action of the waves. Flamborough Head, North Foreland, Beachy Head, and so forth, are examples of regions where the sea has found its progress over the land arrested by relatively hard rocks. Elsewhere, in regions where the rivers furnish abundant débris, we have sand-dunes, and beds of sand and shingle, the Fen region showing the conditions which we have already noted on p. 103. Throughout this area the water fringing the coast is shallow, and much of the force of the waves is spent on the shallow bottom before they reach the shore.

In marked contrast with this eastern region, the south-west, including the counties of Devon and Cornwall, as well as the southern extremity of Wales and the counties of Cork and Kerry in Ireland, is an old peneplain, broken off short where it meets the sea. The region is a part of the old Armorican Mountains, which once stretched from Brittany across the western part of the Channel to Ireland. The fold lines here run in a general east to west direction, and the Bristol Channel and the western part of the English Channel correspond to longitudinal valleys. Before it sank partially beneath the sea this mountain region had been deeply dissected by rivers, and the drowned valleys form

typical rias in Bantry Bay, Kenmare River, Dingle Bay, etc., as well as in Plymouth Sound, Falmouth Sound, Milford Haven, etc.

Further to the north there stretches across the greater part of Ireland, much of Wales, the north-west of England, the southern Upland of Scotland and much of the Highlands, a great belt of country whose fold lines have a general south-west to north-east trend. This belt represents the worn-down remnants of a very old mountain range, the Caledonian Range, which once stretched across what is now the northern part of the North Sea to Norway, and is broken through between Ireland and Great Britain, as well as between Great Britain and Scandinavia. The broken edges of this chain form on the one hand the cliffs which skirt the coast of Aberdeenshire, and on the other the rugged coast-line of the west coast of Scotland with its fiords and inlets. The west coast of Scotland has apparently been more deeply sunk than that of Ireland, for its fiords and sea-lochs are better marked than those of Ireland.

Where, within the area once occupied by the Caledonian Chain, portions worn down nearly to sea-level meet the sea, and this occurs especially in the Midland valley (*cf.* p. 49) owing to faulting, there we have a low coast-line, with, in places, an abundant accumulation of sand. The sand-dunes of Ayrshire, of Forfar and Fife, of parts of the coast of Northumberland, etc., alternate with massive cliffs. Often the sand-dunes have a basis of boulder clay, and must thus be largely ascribed to the action of the ice, which left mounds, on the top of which sand accumulated. Often, also, the beach is fringed by a terrace of sand, gravel or clay, forming a raised beach, and protecting the cliff behind from attack by the waves (*cf.* p. 33). Thus, although the region named was once occupied by the Caledonian Upland, the coast-line is by no means lofty and rugged throughout. Where the old land was greatly worn down, the sea may be fringed by a considerable coastal plain, quite comparable to that which occurs in the eastern part of England, though it is much older and has arisen in a different way, being a plain of erosion, in place of one of deposition, which has typically horizontal beds.

Still further north than the old Caledonian Range, a narrow band of still older rocks, another remnant of a mountain chain, sweeps from the extreme north of Ireland,

through the Hebrides and north-western Scotland, past the Shetland and Orkney Islands to the Lofoden Islands. This is the margin of a sunk land, and the line of subsidence is marked by many rocky islands, and by submerged ice-moulded valleys which form fiords. In this region lofty cliffs are frequent, as is well exemplified in the Orkneys.

CHAPTER VIII

THE WORK OF ICE AND EXISTING GLACIERS

Ice in Lakes, Rivers and the Sea.—Glaciers and their Origin.—The Snow-line.—Characters of Mountain Glaciers.—Ice-cap Glaciers.—Other Types of Glaciers.

Ice in Lakes, Rivers and the Sea.—As is well known, water varies in density with the temperature. The density is greatest at about 39° F. (4° C.), so that the liquid expands if it is either heated or cooled when it stands initially at this temperature. If cooled it expands steadily till freezing-point is reached, and then there is a sudden further expansion as the change of state from water to ice takes place. As has been already suggested, these variations in density, with the corresponding expansion and contraction, have an important effect in assisting in the surface disintegration of rocks, but in addition to thus assisting the ordinary process of weathering, ice has special geological and geographical effects.

In the case of lakes and ponds, ice forms in the following way. The surface water cools to 39° F., and being then heavy sinks to the bottom, its place being taken by warmer, lighter water. The process continues till the whole mass is cooled to 39° F. The upper layers then cool further, and as they now expand they remain at the surface, ice being formed when their temperature falls below 32° F. If the water is shallow freezing may take place throughout the mass, otherwise only a surface covering is formed. In the case of very deep lakes, the temperature of the bottom water in the centre may not sink to 39° F., and in this case the constant circulation of water prevents freezing at the surface, though ice forms freely round the shallower margins of the lake.

Ice itself, like most solids, expands when warmed and contracts when cooled. In consequence, in climates where the winter range of temperature is great, the curious phenomenon of "lake ramparts" appears. This has been described in the colder parts of North America and also in

the continental parts of northern Europe, especially round the Gulf of Bothnia. It will probably be found to occur generally in connection with lakes and enclosed arms of the sea in cold climates. Lake ramparts consist of wall-like masses of stones round the margins of lakes and gulfs; round the Gulf of Bothnia, owing to recent elevation of the land, they sometimes stand at a considerable distance from the present water-line. The mechanism of production is as follows: When a thick layer of ice lies on a mass of cold water, the temperature of the under surface of the ice is kept nearly constant owing to the presence of the water, while the upper surface is exposed to great variation owing to the changes in the air temperature. The upper surface responds to these variations by expanding or contracting, and thus sometimes cracks and sometimes buckles up according as it is contracting or expanding. If the shore upon which it is resting is low, the expanding ice is pushed over its margin, and, besides modifying this margin considerably, often shoves over it loose stones from the shallow water. As it retreats again the ice leaves these stones behind, and they ultimately form the wall-like ramparts. Lakes, as we shall see, are specially common in recently glaciated regions, and then often contain innumerable erratic blocks left behind by the ice. It is these which are pushed out of the lake to form a rampart on its verge. In Finland, where erratics are extraordinarily numerous, the winter ice frequently affects navigation owing to its transporting effect upon the blocks of the shore.

The "ice-foot," which forms in winter round the margins of cold seas, has also considerable transporting power. Owing to its salinity, sea water grows heavier till it freezes at a temperature of about 26° or 28° F. The ice crystals as they form are fresh, but masses of crystallised salt are included in the ice. The marginal ice is often very thick, for the snow which falls upon the shore is included in it. Fragments of rock fall on the surface of this ice, which is jammed by the waves against the shore-line, and doubtless helps greatly in littoral erosion, while portions of it carried away by the waves transport rocks and rock rubbish far out to sea.

Floe-ice is the ice formed on the surface of the sea at a distance from the shore, and fragments of floe-ice when compacted together form ice-pack or pack-ice, which is

often of very irregular form on account of the way in which the blocks are jammed together.

In cold climates rivers also freeze in winter, and the ice greatly assists the water in its work of erosion, especially when melting occurs and the great blocks of ice are jammed against projecting portions of the shore. Stones frozen into the ice may also be carried far down the rivers. When the rivers flow north, like the great rivers of northern Asia, their lower portions may be blocked by ice while the upper parts are running free. The result is tremendous and destructive flooding in the lower reaches, which renders the land unfit for human habitation.

Glaciers and their Origin.—All these effects of ice, however, are geographically insignificant when compared with that of glaciers. Glaciers occur in two main forms, as ice-caps in polar regions and as mountain glaciers in regions of great elevation. Such regions as Iceland and Norway, where we have a combination of great elevation and high latitude, to some extent form a transition between the two, for the existing glaciers in these countries may be regarded as the remains of ancient ice-caps. The general interest of the subject of glaciers is increased by the fact that all the evidence goes to show that a great part of Europe and of North America, as well as, apparently, lands of similar latitude in the southern hemisphere, in regions now largely ice-free, were recently covered with ice, and owe much of their present form to its action.

The origin of glaciers and ice-caps or sheets may be simply explained. When moisture condenses in air the temperature of which is below freezing-point, minute crystals of ice form, instead of minute drops of water, and these crystals cling together and fall to the ground as snow-flakes. On the ground, if the temperature be sufficiently low and the sun not too powerful, they form masses of snow. Such masses of snow, when they accumulate in mountain regions, are partially melted by the sun and warm winds, but it may be that the amount which falls in winter is greater than that which is removed in summer by melting or direct evaporation. In that case the region is said to lie above the snow-line, and will tend to form a snow-field. Snow does not accumulate everywhere above the snow-line, for the slope in many places is too steep for more than a small amount to lie. As fresh amounts are deposited, the friction

of the surface is overcome and the whole mass begins to slide in an avalanche, till it comes to rest in a region of less slope. Almost every snow-covered mountain will show regions where, as can be seen from the whiteness of the surface, avalanches are continually occurring. The result is that great masses of snow accumulate in areas of slighter slope, and here the pressure, combined with the processes of melting and freezing, convert the white snow into compact blue ice, which begins to move slowly down the slope as a glacier. This, in brief, is the origin of mountain glaciers.

THE SNOW-LINE.—Before beginning to discuss details, let us return for a moment to the consideration of the snow-line, the line above which more snow falls in winter than melts in summer. Its elevation varies greatly, from sea-level in the far south and north to about 16,000 feet (5,800 metres) on the north slope of Ruwenzori (lat. 3°). In the Alps the average height of the snow-line is 9,000 to 10,000 feet.

As these figures suggest, there is great variation, and it is noticeable that latitude, though important, is not the sole factor, for the snow-line may differ on the two sides of the same mountain chain, and may lie higher in the tropics than under the equator. This is because the actual amount of precipitation is important, and as the tropics are generally drier than equatorial regions, and the north side of, *e. g.*, the Himalayas drier than the south, we find that in all cases the line lies higher on the dry side or in the dry region than in the area where the annual precipitation is greater. Dryness of the air has a further effect in increasing evaporation, much snow disappearing by direct evaporation. The form of the mountain is also important, for certain slopes are less exposed to the sun than others.

Glaciers only form on mountains in low latitudes when a considerable area of the surface rises above sea-level, and they do not reach any size or importance unless they are fed by extensive snow-fields. Conspicuous mountain glaciers are, therefore, almost confined to the mountains of Scandinavia, the Alps, Caucasus, Himalayas and chains of Central Asia, the great chain of the two Americas, and the mountains of New Zealand, those occurring in other mountain systems being insignificant. Even in the Alps the existing glaciers are for the most part small (*cf.* the size of

those of Switzerland as compared with that of the Victoria Land glaciers in Fig. 40), and the subject of glaciation would not merit the detailed treatment which it receives in all text-books of physical geography, were it not for the fact that the glaciers of the Ice Age had a very wide extension, and have profoundly modified much of the surface of Europe and North America. So short is the time since those old glaciers melted from the low grounds, that the traces of their action are everywhere distinct, and scarcely modified by subsequent denudation.

CHARACTERS OF MOUNTAIN GLACIERS.—A mountain glacier, such as those which exist abundantly in the Alps, is simply described. We have first the snow-field composed of névé, or firn, which often, though not always, lies in a basin-shaped hollow, called a cirque. A cirque is an armchair-shaped niche in which snow accumulates. Above it rise peaks and crests, whose snowfall augments the mass within the niche. But though snow-white in colour the snow-field does not consist of pure snow; in its thicker parts glacier ice already exists beneath the surface snow, and despite its gentle slope the névé partakes in the movement of the glacier. There is usually a distinct region up to which the movement extends, and the junction zone between the two regions is marked by a deep crack or crevasse, called the *rimaye* in the French Alps, but much better known by its German name of *bergschrund*, which has passed into geological literature. The bergschrund runs round the containing wall of the cirque, and is often spoken of in accounts of climbs, for it usually offers a considerable obstacle to the attempt to mount from the snow-field to the peaks which dominate it.

The snow-field, in addition to its somewhat gentle slope, is characterised by its slightly convex profile, but the glacier tongue, which streams from its lower end, is steep and concave in profile. In the Alps the ice-tongue, or glacier in the limited sense, always lies in a valley, whence the name valley glacier applied to this type, which is also called alpine. The glacier valleys of the Alps are now far too big for the shrunken glaciers which they hold, and a great extent of valley, once occupied by ice, is exposed to view. From the rocky walls of the valley, no less than from the peaks above, quantities of stones and rock waste fall upon the surface of the glacier. The slow movement of the glacier causes these to arrange themselves in rows along its side,

where they form lateral *moraines*. Where two glaciers meet, the adjoining lateral moraines form a medial moraine.

But the great masses of stones and fine rock-flour, which are so conspicuous near the lower ends of the existing glaciers, are not only due to the effect of frost and weathering on the uncovered rocks above the glacier; the glacier itself has a marked effect upon the rocky bed over which it flows. To understand how this occurs we have to remember that the glacier is moving, even if very slowly (a foot a day is a not uncommon rate), and is moving down a valley of varying slope. Where the slope increases the ice becomes deeply fissured, huge crevasses forming. Sometimes, when the slope is great, numbers of crevasses occur in all directions crossing each other, and thus ice blocks and pillars of varied forms, called *séracs*, are formed, and the glacier presents the appearance of an ice-fall. A considerable amount of surface water is always formed by melting, and quite often streams are produced which flow on the surface of the ice till they meet a crevasse, and are then engulfed, carrying with them stones and rock waste. As it plunges into the crevasses the water takes on a rotatory movement, and whirls its load of stones round as it rushes through the ice. The result is to form a pipe, called a glacier mill (*moulin*). From the examination of old glacier beds we know that the whirlpool of water not only reaches the base of the glacier, but acts upon the subjacent bed of rock, where it hollows out a giant's kettle, or glacier mill, the equivalent of the pot-holes of a stream bed.

As a result of these movements of water, a large amount of rock rubbish finds its way beneath the glacier, and there the stones, etc., are frozen into the ice, and act as graving tools in the wearing away of its rock-bed. The slow scraping of the stones grinds down the subjacent rock, forming rock-flour, the process being called abrasion. It is this rock-flour which gives glacial streams their turbidity (*cf.* p. 94). Further, it is believed by many geologists that the ice, aided by frost, actually removes pieces of rocks from the surface of its bed, by a process called plucking. When a rock mass in the bed of a glacier offers an obstacle to its flow, the ice tends to wear away the rock by abrasion on the up-stream side, while deposition takes place on the down-stream side. The difference between the two is so marked that names are given to the two sides of the obstruction,

the upper steep side being called the *stoss* side and the lower the *lee* side. The result is to form a hollow in front of the rocky obstruction, and a long "tail" of waste on the lower side. The name of crag and tail is given to the appearance so produced. The rock on which Edinburgh Castle stands is a good example, the tail forming the High Street.

In addition to the crevasses, one other surface feature of glaciers merits a few words. The surface, especially where the valley is narrow, may receive a large amount of rock dust, no less than stones of all sizes. The small stones and the dust soon come to occupy hollows in the ice, each pebble or collection of dust particles lying in a dust-well. The reason is that the solid particles are heated by the sun, and melt the surrounding ice. The process may go on until quite deep pools are formed on the surface. On the other hand, if the stones are very large, they protect the ice beneath from the sun's rays, while being themselves too large to be heated through. In that case the surrounding ice melts, and the block of stone remains supported on a pedestal as a "glacier-table." The same effect is produced if small stones are so near together as to touch one another. Thus moraines often consist of ice protected from melting by the enormous mass of material on top of them.

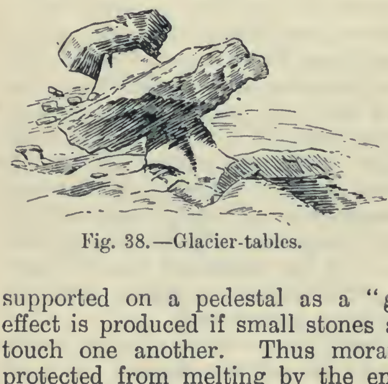

Fig. 38.—Glacier-tables.

The first phenomenon, the melting effect, is well known to Swiss peasants, who place flat stones on their pastures in spring to ensure rapid melting of the snow, and it is stated to have been employed in the construction of the Bergen railway, where it was found that a light sprinkling of sand or earth caused very rapid melting of the snow-drifts, which otherwise would have had to be shovelled away.

The net result is that the glacier carries down its valley an enormous load of waste, derived both from the peaks and crests which rise above it and from the surface of its bed. This load is spread out in front of it at the point where the ice melts away, and the sub-glacial water emerges from the

Fig. 39. The Ice-cap of Greenland.

terminal ice-cave as a rushing torrent. This torrent sorts and re-arranges the glacial material, and carries the finer parts far down the valleys, to be deposited on alluvial plains. The fact that all the valley glaciers of the Alps are but shrunken remnants of their former selves means that the moraines at present forming are insignificant compared with those of the old glaciers, which occur far from the present terminations of the glaciers. But to this point we shall return.

Ice-cap Glaciers.—Let us turn next from the consideration of such an alpine glacier to the ice-cap type, as it is represented in the Far North and South. The essential point here is that the thickness of the ice is so great compared with the size of the underlying topographical features that these have no apparent effect upon the movements of the ice. As our first example we may take the inland ice of Greenland, which is now tolerably well known, thanks to many expeditions. This ice-cap has the form of a flat dome, and envelops the whole of the continent save for a narrow marginal rim. The width of the rim varies greatly. It is absent from the heads of the deep fiords, for here narrow ice-tongues push out into the sea. It is very narrow over considerable areas in certain localities, notably in Melville Bay (below Mt. Haffner on map), where the ice is close to the sea for about 150 miles. Elsewhere it varies from a usual width of 5–25 miles to a maximum of 60–100 miles. Only near the margin of the ice-cap on the rim does any uncovered rock appear. All the centre is a dreary waste of snow. "It is an Arctic Sahara," says Peary, "in comparison with which the African Sahara is insignificant. For on this frozen Sahara of inner Greenland occurs no form of life, animal or vegetable; no fragment of rock, no grain of sand is visible. The traveller across its frozen wastes . . . sees outside himself and his own party but three things in all the world, namely, the infinite expanse of the frozen plain, the infinite dome of the cold blue sky, and the cold white sun—nothing but these."

In this region there can be no sub-aerial denudation, for no rock is exposed. As in desert regions the wind acts with great force, and as a result of its action it forms hummocks and ridges in the snow and ice, which are of great importance to Arctic travellers, and receive the general name of sastrugi.

Fig. 40. The edge of the Antarctic Ice-cap in Victoria Land. Note the great size of the glaciers, especially of the Beardmore Glacier.

Very different is the appearance of the margin of the ice-sheet. Near this margin the mountains pierce the ice, and appear at the surface as rock-islands or nunataks. In front of this region appears the ice-free portion of the continent, the inland ice often ending very steeply on the seaward side in a series of terraces or steps. The exposed portion is mountainous, and between the mountains tongues of ice descend to enter the long fiords which run up into the land. As these ice-tongues push their way into the sea, icebergs of irregular shape are calved off from their extremities, and float away in the sea water. The ice in these ice-tongues moves at remarkably rapid rates, up to 100 feet in 24 hours having been measured, while the rate of movement of the inland ice is very slow. In regard to moraines, it is obvious that surface moraines can only occur to a very limited extent near the margin of the ice, for only here is rock exposed in the nunataks. But where the ice-cap ends in a vertical cliff, it is easy to see the ground or bottom moraine near its base, consisting of material which has been removed from the rock surface over which the ice has travelled. It is noticeable that the terminal moraines formed in front of the ice-cliff consist chiefly of blocks of stone, with but little admixture of fine material, and they become very compact. Another contrast with alpine glaciers is that conspicuous streams of water do not appear from beneath the ice-cliff. Lakes are common round the ice-margin, being often produced by the damming back of water by compact moraines, or by tongues of ice.

The ice-cap of the Antarctic area offers in some respects a contrast with the inland ice of Greenland, in that it is noticeably larger than the land surface which it covers, and spreads out to the sea at all sides. The great ice-plateau of the interior seems comparable to the ice-plateau in the interior of Greenland, but the margin offers some interesting features. The first point of interest is the occurrence of what is called Barrier ice round the edge of the continent. The term is unsatisfactory, for while it is admirably descriptive of the appearance presented by the margin of the ice (the Great Barrier), it does not indicate the great extent of level ice which stretches round the edge of the Antarctic continent. The term shelf-ice has, therefore, been applied to the ice-field whose margin forms the Barrier.

Ross sailed for 500 miles along the front of a great wall

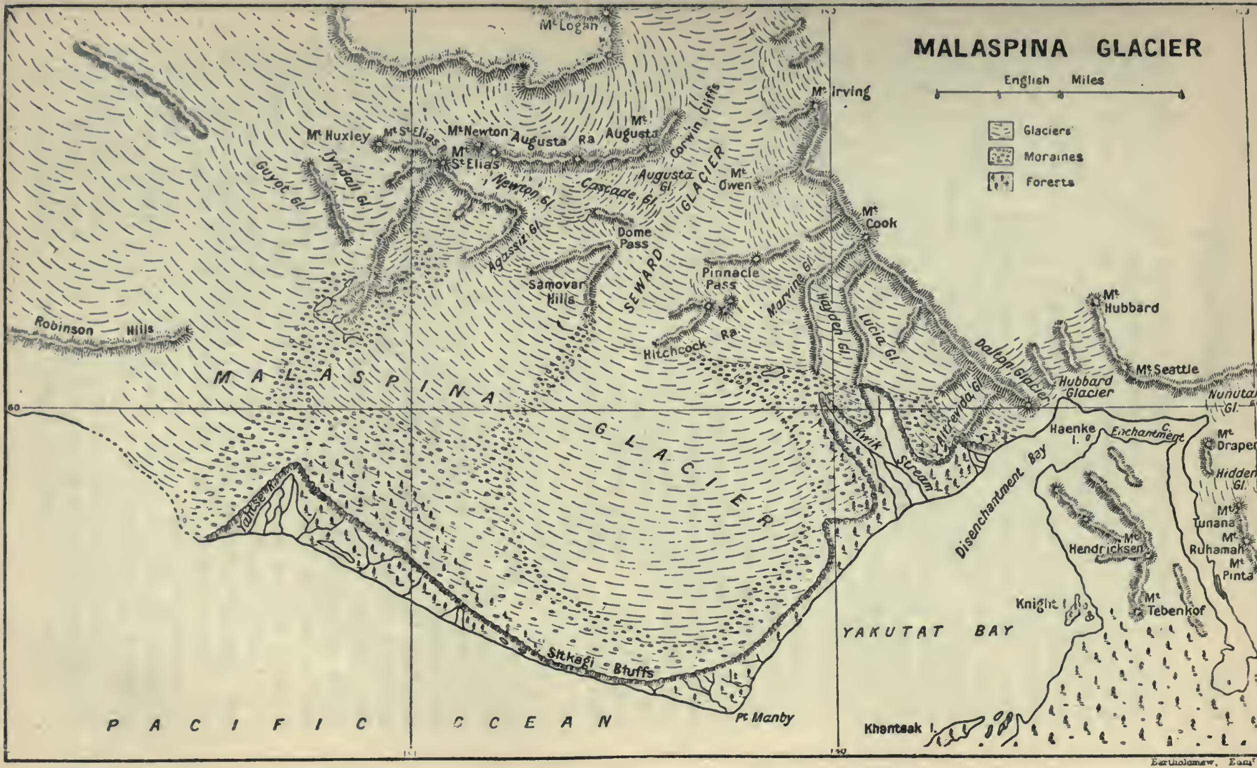

Fig. 41. A Piedmont Glacier, or Ice-apron, made of the union of many glaciers on a coastal plain.

of ice in the Ross Sea, which appeared of almost uniform height. Closer study has shown that the height here varies from 50 to 280 feet, and behind the wall-like edge there stretches a wide, almost level, shelf of ice. When examined in detail the shelf is found to consist of compacted snow rather than of true ice, and it appears to be afloat. From its seaward margin huge flat-topped icebergs are given off, which float away as the characteristic tabular bergs of the Antarctic. When followed landwards the ice-shelf is found to be fed by huge glaciers (see Fig. 40), which descend from the inland ice through gaps between the coastal mountains of Victoria Land. But the greater part of the shelf appears to be due to snow falling upon its surface, and it is thus largely a névé giving off icebergs in place of glaciers. In other parts of the Antarctic area similar if smaller ice-shelves occur, and they may be said to be characteristic of the Antarctic area.

In Victoria Land, as just stated, the lofty coastal mountains pierce the ice-sheet, like the nunataks of Greenland, and between the peaks huge outlets allow glaciers to escape. In Kaiser Wilhelm Land, on the other hand, there are no such lofty coastal mountains, and with the exception of the volcanic peak of the Gaussberg, no part of the surface is left uncovered by the ice. Here the ice enters the sea in a continuous sheet, and imitates the conditions which are believed to have prevailed in Northern Europe during the Ice Age.

Other Types of Glaciers.—A number of other types of glaciers have been described by various authors, but in essence they are all transitional between the ice-cap type and the alpine type. Thus in Norway we have a special type variously called the plateau type and the ice-field type. Here a dome-shaped cap of ice occupies an internal plateau, and resembles a polar ice-cap, despite the small size, in that no rock surface appears above its level, and surface moraines are, therefore, necessarily absent. From the ice-field many ice-lobes stream out as glaciers, forming the *ice-streams* of the Norwegians. The Jostedalsbrae, from which no less than twenty large glaciers arise, is a good example. Similar types occur in Iceland and Spitsbergen, their presence being determined by the fact that the high ground is a recently-elevated peneplain, from which all marked topographic features have long since been worn away.

In Alaska, where also there is heavy precipitation, the

topography gives rise to another type. Here we have recently elevated mountain chains of very strong relief. Thus the crests are too lofty, the valleys too deep, for the whole range to be drowned in ice, and therefore in the centre of the range many peaks and ridges stand up above the ice-field. But as the ice-streams reach the lowlands they come to a region of less marked relief, and here they fuse together, forming huge ice-sheets. This is beautifully illustrated in the case of the Malaspina glacier. Ice-aprons of this kind in front of lofty mountain regions are called by American geographers piedmont glaciers, and on account of the numerous rock surfaces exposed on the higher ground they necessarily spread out an enormous amount of rock waste over the low ground. The great interest of this condition is that it occurred in the Alps, as well as elsewhere, during the glacial period. The Alps resemble the mountains of Alaska in their recent origin and in their general form, and the effect of the lowered temperature of the glacial period must have been to produce essentially the same conditions as regards the arrangement of the glaciers.

Another very interesting point is illustrated in the mountains of Alaska to-day, as it was in the Alps of the Ice Age. This is that a branch of a glacier issuing from an ice-field may over-ride the wall of a valley, and thus stream out in an opposite direction to that in which the main ice-stream flows. In Alaska these "through glaciers" form convenient means of crossing the mountains. When the ice melts away, as we shall see later, their result is to leave a pass by which the mountains can be easily crossed. In the Alps the Rhone Glacier once not only streamed down the great valley now called the Valais (p. 70), but also sent an arm over what is now the Grimsel to pass down the Haslital, or Upper Aare valley (Fig. 21), so that the same great ice-field sent water alike to the Rhone and Rhine drainage systems.

In the above descriptions we have laid special emphasis on the conditions prevailing in the Alps, because their glaciers are most easily studied and are most familiar. But we must not forget that the existing Alpine glaciers are excessively insignificant, and in place of filling the valleys in which they once lay, occupy often the merest niche at the top of the valley. It is well to keep this fact of their present insignificance prominently in mind, when we come to consider their past in the next chapter.

CHAPTER IX

THE EFFECT OF THE ANCIENT GLACIERS ON THE SURFACE

The Pleistocene Glaciers of Northern Europe and their Effects as Eroding Agents.—Glacial Deposition in Northern Europe.—The Alpine Glaciers in the Ice Age, and their Effects.—Cirques.—Glacial Deposits in Alpine Regions and the Alpine Lakes.—Origin of Lakes.

THE PLEISTOCENE GLACIERS OF NORTHERN EUROPE.—We have now noted the chief characteristics of glaciers, and it is necessary to turn next to the consideration of the question of their effect upon the surface, and here we are greatly assisted by the recent passing away of the Ice Age (or Pleistocene period), which has left such marked traces of its existence. In the north of Europe and America the old glaciers were apparently of the ice-cap type. Further south powerfully developed mountain glaciers clothed such chains as the Alps and Pyrenees, and deployed as piedmont glaciers on the low grounds at their base, where they have left their traces far out on the plain. In the one case only a few peaks and knolls probably protruded through the ice-sheet as nunataks, in the other a great part of the mountain crests and summits must always have projected above the glaciers and névés, as we can deduce from their sharpened forms, which show no trace of ice action. But we have to remember that before the onset of the Glacial period there was a marked difference between the topography of such regions as Scotland and Norway on the one hand, and the Alps and Pyrenees on the other. In the former case much of the land consists of a recently-elevated peneplain, in the other we have folded mountain ranges of recent origin. It is, therefore, not altogether easy to determine how much of the present difference betwen the two regions is due to the action of ice, and how much to the influence of the pre-glacial topography.

ERODING EFFECT OF PLEISTOCENE GLACIERS.—A very short account of the present topography of the more northern

parts of Europe may suffice to indicate the apparent effects of its old ice-cap. Beginning with the region completely drowned in ice, the first point to be noticed is the general rounding of the forms. Individual rocky projections have that ice-smoothed appearance described by the term *roches moutonnées*, and on the large scale the mountains themselves show the same tendency to rounded forms. The valleys are broad and open, and what are called "through valleys" (p. 123) are frequent; in other words, the divides are low, so that marshy regions are common. It is quite usual to find that the broad open main valley is deeper than the lateral valleys, so that the tributary streams enter by waterfalls or through gorges. The lateral valleys are then described as "hanging." In Scotland, Wales and Norway, as well as elsewhere, cirques are a conspicuous feature of the uplands, their floors being often covered with tarns.

To the general uniformity of outline the fiords of the Scottish and Norwegian coasts form an exception. Here the topographical features are well marked, the deep, steep-sided fiords having hanging valleys opening into them, and often showing sharply-cut mountains near their edges. These are associated with two special features of these regions. First, we have the fact that the Ice period was not continuous, for inter-glacial periods occurred, when the ice-cap shrank, and mountain glaciers of the ordinary type appeared, which had their usual accentuating effect upon the relief, as compared with the smoothing action of the ice-cap type. Second, as the strand-lines of Norway show, there have been considerable movements of elevation and depression in the region of the fiords. Apparently the fiords themselves mark old lines of crust weakness, which were taken advantage of by pre-glacial rivers. The mountain glaciers which occurred in inter-glacial times, or during the final passing away of the ice-cap, gave these valleys their characteristic form (*cf.* p. 105), and subsequent movements of depression converted them into arms of the sea. As de Martonne notices, if the Adriatic were to extend across the plain of the Po, then Garda and the other Italian lakes would become fiords.

Deposition in Northern Europe.—The above features are due to the eroding effect of the Pleistocene glaciers, but we have to note also their effects as depositing agents, specially marked on the low grounds, or, as we may call

them in relation to the centres of the active glaciation, the peripheral regions. In the first place the old ground moraine of the ice-sheet forms a thick deposit over the low grounds, where it constitutes the familiar boulder clay so widely spread in Scotland, in England north of a line between the Thames and the Severn, in Germany, Sweden, parts of the United States and elsewhere. This tough, tenacious clay has numerous ice-scratched stones scattered through it, as well as occasional large blocks. The names of drift and till are also applied to it.

But apart from the occurrence of boulder clay in regions like Scotland, where the low grounds have as it were recovered from the effects of glaciation, we have regions where the glacial deposits remain all but unaltered by subsequent denudation, and a characteristic morainic topography is produced. We have already mentioned the Dombes in France as an example of this, but we may note that the extreme north-east of Prussia, Finland, and much of the region in the vicinity of the great lakes in North America, show similar conditions.

Over all these regions great lobes of ice once lay, and discharged in front of their extremities confused masses of glacial material. Let us take first the case where such an ice-lobe remained stationary for a prolonged period, the melting in front being just balanced by the flow of new ice from behind. At the extremity of the ice the lateral moraines, consisting largely of angular blocks, would mingle with the fine rock-flour and the smoothed and striated stones of the ground moraine. The result would be to form a kind of embankment round the margin of the ice, an embankment which would present its concave surface to the glacier, and its convex surface to the low ground. This outer surface would be furrowed by innumerable torrents originating from the melting ice, and these would spread the finer particles of the moraine far and wide over the low ground. Within the embankment, or frontal moraine, as it is called, many minor heaps of morainic matter would accumulate. When the ice finally melted away, we should have an irregular surface, sprinkled with many morainic mounds, and therefore holding innumerable lakes, whose waters are dammed back by the barriers formed by these mounds. For a time the huge arched frontal moraine would persist, and in front of this will extend a vast alluvial plain, floored by the finer

parts of the morainic material, forming the "outwash plain" of American geologists, the *sandr* of others.

In Finland the frontal moraine is beautifully marked, and forms the long ridge called the Salpausselka (see Fig. 42). Behind it lies a region which has well earned its name of "country of a thousand lakes," even if fluvial erosion is

Fig. 42. Sketch-map of Finland to show the terminal moraine, forming the long mound called the Salpausselka, behind which lies a second mound, the inner Salpausselka.

These mounds run at right angles to the old glaciers, but the œsar, also shown on the map, run parallel to the existing lakes and streams, as they ran parallel to the old glaciers.

beginning to fill up some of these, empty others, and generally readjust the disturbed drainage. While many of these lakes are simply moraine-dammed masses of water, others seem to lie in true rock basins, apparently excavated by the ice. Such rock basins are not infrequent in glaciated regions, though it is still uncertain whether they owe their origin entirely to the excavating power of ice.

But the frontal moraine does not always persist in this

form. Apparently it has often happened that the extremities of the old glaciers underwent many movements of advance and retreat, with the result that the frontal moraine of one stage was again overridden by the ice, so that an extraordinary confusion of deposits occurs. But the general features remain the same—that is, we have a region of morainic topography with an outwash plain, or sandr, in front.

Not infrequently glacial deposits, especially when rearranged by water, occupy mounds of very definite form, to which special names are given. In Scandinavia and Finland long, winding ridges called œsar occur (see Fig. 42), which are often joined by minor ridges, just as a river is joined by its tributaries. It is believed that these mark the position of sub-glacial streams, in which copious deposits of sand and gravel were laid down. When the ice melted away, the position of its old sub-glacial torrents was marked by these deposits, which form the winding ridges, and consist of material which shows water action. The terms kame and esker are also applied to this condition in different countries, but in Scotland the word kame is also used for mounds having a different origin, some of the Scottish kames being parts of terminal moraines, whose contents have been to some extent water-worn. Such mounds run at right angles to the direction in which the ice flowed, while œsar are parallel to the old glacier.

Still another type of morainic mound occurs, this being formed by the peculiar elongated hills called drumlins, which are often very numerous, especially in the United States. They consist largely of clay which shows signs of great compression, and when they occur are very numerous, and have their long axis arranged parallel to the direction of the flow of the ice. They are specially abundant in the north of the State of Wisconsin in the United States, and are believed to be fragments of the ground moraine, compressed by ice movements, and owing their characteristic shape to this fact.

THE ALPINE GLACIERS IN THE ICE AGE.—As contrasted with the effect of the ice-cap in the more northerly parts of Europe and America, we have to consider next the effects of the large glaciers of the Ice Age on the mountain ranges in which they occurred. It is in the Alps that these effects have been most carefully studied, and here, as in the former case, we may distinguish between the central region, where

erosion is at its maximum, and the peripheral region, where deposition is very important.

Cirques.—The first point to be noticed is the formation of cirques. These are by no means universal in the Alps, being indeed uncommon in the Central region, but they are well developed in the Pyrenees and in the eastern Alps, and may be regarded as one of the characteristic features of glacial erosion in regions where the whole landscape is not drowned in ice and snow. Their development in regions like Norway and Scotland, which once had an ice-cap, is to be explained by the existence of inter-glacial periods when the ice-cap must have shrunk enormously, and also by the existence of a long period during which the ice was steadily diminishing, and no longer formed a cap.

The exact origin of cirques is still a disputed matter. According to the American geologists it is especially due to basal sapping at the bottom of the bergschrund. This great crevasse allows warm air to penetrate down to the rock surface on which the névé rests, and melting ice and snow supply in summer continual moisture. The consequence is that frost work is here very active, and as the ice which bounds the bergschrund on the down-stream side is moving, rock waste is carried away as it forms, and a new surface is exposed to frost action. The first beginnings of the cirque are similarly ascribed to the action of frost round the margins of snow-banks lying on hill-sides. As in the fully formed cirque the wall tends to be cut back all round the curve of the armchair-shaped niche, and as many cirques may lie side by side, the tendency is for the cirques to unite, so as to form a broad mountain shelf. Similarly, the cirques on the two sides of the mountain eat back their walls, so that they may unite and form a col through the chain. At the same time the crests which rise above the cirques are always tending to be sharpened and dissected. A continuation of the process may largely destroy the original armchair effect.

As the glacier streams down from its cirque it hollows out its bed, so that this comes to have a trough-like shape. While many Alpine glaciers at the present day occupy only the upper part of this trough, their predecessors extended far down the large U-shaped valleys, to melt away finally on the low grounds beyond. These U-shaped valleys are very characteristic, and contrast markedly with the V-shaped

valleys in which most rivers run. In the Alpine valleys, formerly occupied by ice, we find that the bottom is broad and generally flat (*cf.* the Rhone valley in Fig. 22), though the existing river may be beginning to cut a new V-shaped valley on the flat bottom. At either side rise steep walls. So soon as a certain elevation is reached, however, the slope changes suddenly, and we have an alp or mountain pasture, covering a region of relatively gentle slope. Above this lies the steep, non-glaciated mountain-side. Across the alp run the tributary streams, which plunge over the cliff into the main valley, and thus form hanging valleys. The figures which show parts of the Upper Rhone valley and the Grésivaudan valley (pp. 71 and 83), illustrate this condition, and the large alluvial fans in the Rhone valley, of which an example is shown in Fig. 22, owe their size to the sudden check to the velocity of the lateral stream as it enters the main valley after leaping over the cliff. We have already spoken (p. 73) of the human importance of these fans.

Another important feature of the glaciated valley is that it shows, much more markedly than the ordinary river valley, that tendency to the alternation of regions of steep and gentle slope of which we have already spoken. Many glacial valleys are like gigantic staircases, the steps being often occupied by lakes, which are sometimes moraine-dammed bodies of water, and at other times perhaps true rock basins.

Another feature directly related to the action of the old glaciers is the presence of numerous passes, often of great importance in human life. These are, as already stated, often due to the extension of arms of an old glacier over a watershed, and they are so abundant in the Alps that these have never in practice served as great barriers to human movements, as one might suppose from their elevation they would do.

Glacial Deposits in Alpine Regions and the Alpine Lakes.—In regard to their action as agents of deposition, the old mountain glaciers acted much in the same general fashion as the glaciers of higher latitudes. A special feature is the great abundance of beautiful lakes now left where the mountains sink into the plain, and called from their position Marginal lakes (*Randseen*). These do not wholly owe their origin to the ice, but their size is increased by the morainic mounds which lie in front of them, and, in addition, the

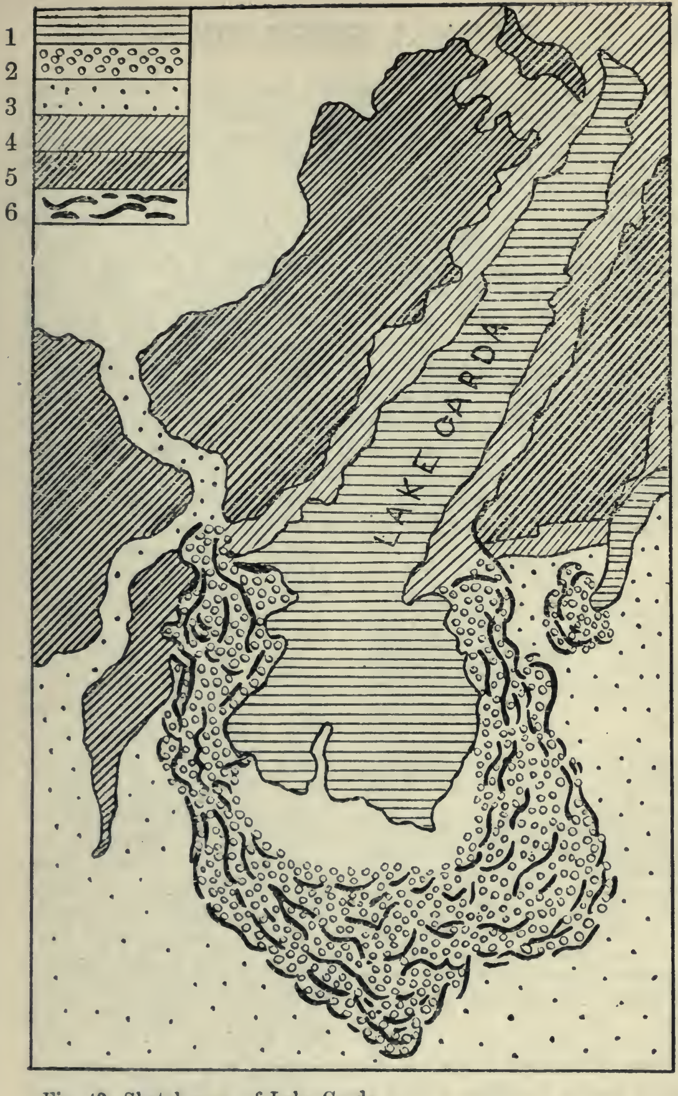

Fig. 43. Sketch-map of Lake Garda.

(1) The area covered by the present lake. (2) The morainic matter which forms the "apron," including (6) the terminal moraines of the old glaciers. (3) The Sandr or "outwash" plain, formed by river and stream action. (4) The rock surface once over-ridden by the ice, as distinguished from (5) which indicates the parts of the surrounding mountains which were never ice-covered. (After Penck and Brückner.)

old glaciers seem to have deepened the basins in which they lie. The shape and size of these morainic mounds suggest that the glaciers which gave rise to them were of the piedmont type. The accompanying diagram of Lake Garda suggests what occurred. The great glacier which once deployed on the low ground at the foot of the Alps here spread out into a huge ice-apron. The front of this apron is indicated by mounds which correspond to the old frontal moraine, shown by dark lines. Within the area once covered by the apron glacial débris is spread out, and its effect is to dam back the water issuing from the Alps, and so form a lake. But the lake is too deep to be ascribed to this cause alone; it lies in a trough due primarily to earth movements. The lake does not, however, occupy the whole of the trough, but only a part of it, which is believed to have been deepened by ice action. It is believed that such lakes as Sempach and Hallwyl owe their origin exclusively to morainic dams, but in the case of all the larger Alpine lakes earth movements have played a part, as has probably, also, direct excavation by ice.

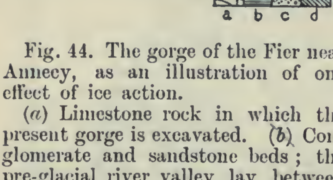

Fig. 44. The gorge of the Fier near Annecy, as an illustration of one effect of ice action.

(*a*) Limestone rock in which the present gorge is excavated. (*b*) Conglomerate and sandstone beds; the pre-glacial river valley lay between these beds, but was filled up by morainic matter (*c*) and gravel (*d*), with the result that the post-glacial stream was forced to excavate a gorge in the limestone. (After Penck and Brückner.)

Another interesting effect of the old glaciers is the blocking of former river valleys by glacial débris, with the result that the post-glacial streams have been obliged to excavate new channels for themselves. Not infrequently these new channels take the form of gorges, called *epigenetic*, from their origin; such gorges being a striking feature of recently glaciated regions (see Fig. 44).

The Origin of Lakes.—As reference has frequently been made above to lakes which have arisen in connection with the action of ice, it may be worth while to sum up briefly the chief causes of the formation of lakes.

Lakes frequently arise in connection with temporary

obstructions to the flow of rivers. Thus at flood-time many rivers form lakes in the wider parts of their valleys because the water supplied by the upper tributaries cannot be carried off with sufficient rapidity by the ordinary channel. Rivers may also be partially blocked by landslips or rock falls, or by the freezing of their lower reaches (*cf.* p. 112), or by the presence of a specially hard rock across the valley, so that lakes arise. Again, meanders may be cut off to form ox-bow lakes (*cf.* p. 89 and Fig. 31). All such lakes tend to be shallow and temporary.

In connection with glaciers, lakes may arise in many ways. A glacier may block a stream entering from a side valley and so cause a lake. The Märjelen See in the Alps, which is barred by the Aletsch glacier, is one of the best-known examples. It periodically disappears as the water finds its way through the barrier of ice. Again, a stream flowing down a valley may be blocked by the moraine of a glacier which once advanced across its valley. The Lac de Combal in the Allée Blanche is a good example.

As has been just explained, also, lakes often form over the site of an old piedmont glacier, owing to the blocking of the streams by morainic material. All the largest and most important of such lakes, however, occur in valleys which seem to be due primarily to earth movements. Not only the large *Randseen* of the Alps, but also the Great Lakes of North America owe their origin to these two causes, in combination with direct excavation by ice in the previously existing trough.

Other lakes of glacial origin are those which lie in regions of morainic topography, and owe their persistence to the difficulty which streams find in establishing a well-defined drainage system over areas covered with soft, impermeable beds (*cf.* p. 92). Other glacial lakes—for instance those of Scotland, Wales and the Lake District of Cumberland—are believed by many geologists to lie in rock basins wholly excavated by ice. Others believe that morainic deposits are important in damming back some of these, and that earth movements have played a part in forming others, notably the deep lakes of Scotland.

Other lakes occur in connection with volcanic regions (*cf.* p. 11). Some of these will be considered in the next chapter. Finally, as we have already suggested (p. 49), some lakes, such as the great African lakes, seem to be the direct result of earth movements.

CHAPTER X

VOLCANOES, EARTHQUAKES AND LAND MOVEMENTS

Effect of Volcanic Action.—Some Typical Volcanoes.—Vesuvius and Mauna Loa.—Distribution of Volcanoes.—Solfataras, Geysers and Thermal Springs.—Effects of Denudation on Volcanic Cones.—Earthquakes.—Evidences of Elevation and Depression.

Effects of Volcanic Action.—In the foregoing chapters we have been considering the effect of the various agents of denudation upon the surface, and it has been obvious that all these agents, as time goes on, tend to act with diminishing intensity. River action, for example, is most intense on land which has recently risen above the surface of the waves; the longer the streams continue to act the slower does their action become, until the period which we have called old age is gradually reached, when their effect is minimal. At this stage waterfalls have disappeared, lakes have been filled up, rapids have been smoothed out, valleys have been widened, and, unless earth movements intervene, the work of the stream is over. The same thing tends to occur with the other agents of denudation, and the result is that the particular region concerned becomes progressively less fitted for human activity. We have already seen, for example, that basins of inland drainage, which are regions where erosion has reached its minimum, are regions specially unfitted for habitation, apparently destined to remain apart from all the great movements of civilisation. But the whole globe would tend to be reduced to this condition were there not agents which interrupt the normal cycle of erosion, and give new powers to the dwindling forces of denudation. One such agent is volcanic action, which we have to consider in this chapter.

A volcano is defined as an apparatus whereby the surface of the earth is put into communication with heated rock in the interior. Its primary constituent is therefore necessarily a vent or opening through which this communication is effected. But as solid or molten matter is ejected through

this opening, the second element is obviously the material ejected, and as this is the more conspicuous of the two, the name volcano is often applied to the heap of material shot out, which usually forms a conspicuous hill or mountain. Nevertheless, it is the vent or channel of communication which is the essential part of the volcano.

Before turning to the consideration of the general features of volcanic action, let us note for a moment the ways in which it influences the ordinary forces of erosion. A reference to the account of the Alban Hills (p. 11) will help to illustrate this. The first and most obvious result, as has just been said, is the accumulation at the surface of ejected material which may form a conspicuous mountain, usually displaying a characteristically conical shape. Thus, while ice, the atmosphere and running water work together to plane away hills and mountains, volcanic activity builds them up anew. Again, as was shown in the case of the lake of Nemi, the formation of lakes is frequently associated with volcanic activity. Thus, while the effect of running water is to fill up lakes, volcanic activity reverses this effect by forming new hollows in which water accumulates.

But while these are the most obvious effects, others which are no less important occur. The material thrown out at the volcanic vent may block drainage systems, and thus force the streams to excavate new valleys for themselves. It may, like the volcanic material which floors the Campagna, raise what was once a sea floor above the level of the waves, while at the same time covering it with an impermeable deposit. In short, not in one but in many ways volcanic activity may lead to a rejuvenescence of worn-out streams, may interrupt the slow but steady progress of the cycle of erosion. It is to be noted, however, that volcanoes are characteristically intermittent in their action. Bursts of activity alternate with periods of passivity during which the forces of denudation recommence their slow but irresistible work, striving, as it were, to obliterate all traces of the one catastrophe before another intervenes. It is noticeable, also, that, as will be considered in more detail later, volcanic activity has at the present time a somewhat limited distribution over the surface. Striking as its effects are, therefore, their extension in space is limited.

Some Typical Volcanoes—Vesuvius and Mauna Loa.—The general characters of volcanoes may best be realised by

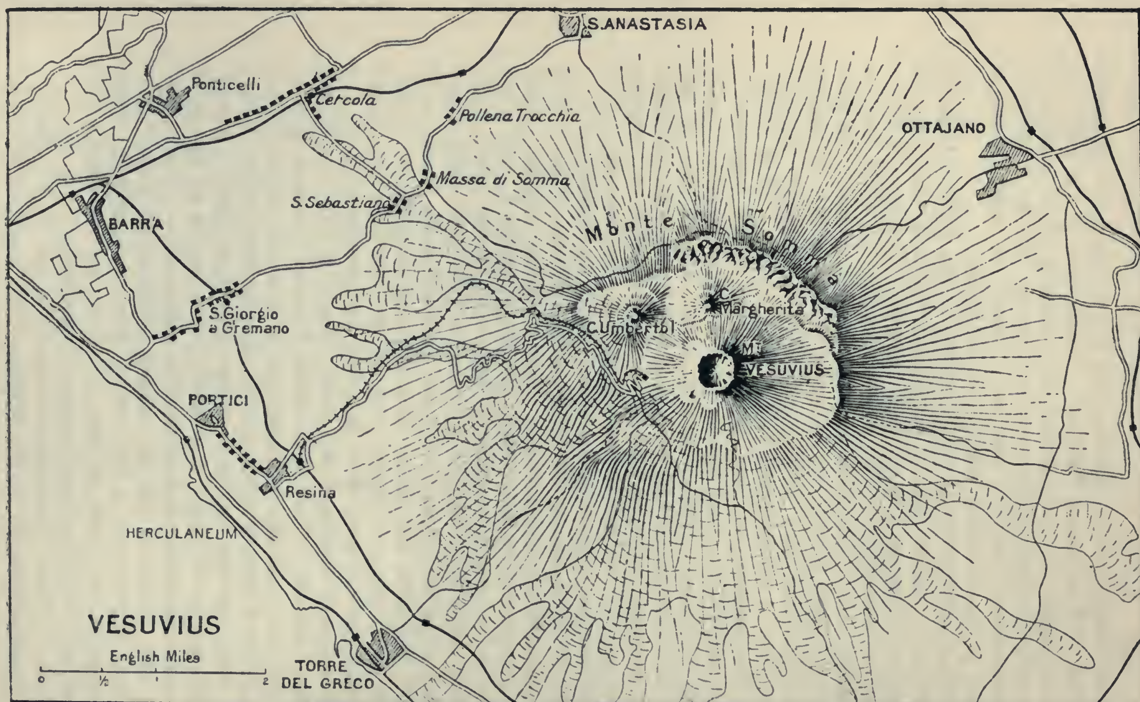

Fig. 45. Sketch-map of Vesuvius. The central depression is the remains of the old crater, part of whose rim persists as Monte Somma. On the floor of this old crater is visible the present very much smaller vent, circular in shape, as well as two small subsidiary craters. The recent lava flows are shown by cross-shading; note their distribution and the characteristic forking which often results in the saving of a threatened village, an event regarded by the peasants as miraculous. Torre del Greco has more than once been severely damaged by lava, while Ottajano suffered, so late as 1906, from clouds of "ashes," which killed many of its inhabitants.

the description of one or two typical examples. We may take first Vesuvius, a case more or less familiar to all. Vesuvius is a conical mountain about 4,000 feet high, situated on the shore of the Bay of Naples, and built up of material ejected from a volcanic vent. Volcanic activity manifests itself intermittently, the mountain having been quiescent for a prolonged period prior to 79 A.D., when the important eruption which destroyed Pompeii and Herculaneum took place. Before that date the summit of the mountain contained a hollow some three miles in diameter, bounded by steep slopes. Such a hollow is called a crater, and represents the vent or opening of the volcano. Before the great eruption of 79 A.D. the sides and even the floor of the crater were overgrown with vegetation, thus indicating that the vent was plugged with solid rock. When activity re-commenced this plug of rock was blown out in a tremendous explosion which destroyed also half the rim of the crater. No lava flow occurred, but the comminuted rock fell as fine dust or volcanic ash. As enormous falls of rain accompanied or followed the explosion, the ash was converted into streams of hot mud which spread far and wide. Much of the dust, however, fell near the summit of the cone, and this upper region is found to consist exclusively of fragmentary materials—that is, of coarse and fine particles of rock, the coarser being called bombs and lapilli, and the finer dust or ashes.

The period of activity thus inaugurated has, as already suggested, continued, with intervals of quiescence, till the present day, and the phenomena which accompany and precede the eruptions have been carefully studied. The crater now contains hot rock, over whose surface, from innumerable small vents, poisonous gases are given off. Much of the rock in the crater is crusted over, but here and there areas where it is molten can be seen. Such molten rock is called lava, and from such boiling cauldron-like patches hot rock-fragments are continually thrown up into the air, accompanied by discharges of steam and gases. The effect of these continuous trifling explosions is to cause a cloud to hang over the mountain, caused by the steam and gases which are being continually given off.

Phenomena of this kind occur more or less continuously, though with varying degrees of intensity. But when an actual eruption occurs various additional facts are observable.

One symptom of the approaching cataclysm is the drying up or diminution of springs in the neighbourhood, even if the rainfall has been heavy. Another symptom of increasing activity is the sudden and enormous increase in the size of the cloud which hangs above the crater. This acquires a characteristic shape, variously compared to a cauliflower and an Italian pine-tree. About the margin of the cloud lightning plays, and from it torrential rain descends. At night the under surface of the cloud is lighted up by reflection from the glowing lava in the crater beneath, so that it appears as though on fire. Earthquakes and rumbling noises occur, and showers of fragmentary matter are ejected from the crater, the dust sometimes forming a snow-white covering over the whole of the upper part of the mountain. Lava does not, as a rule, flow from the main crater, but small rifts open on the flanks of the mountain, from which streams of lava flow out. As these streams of liquid rock flow slowly over the ground they cool and crust over in front, the result being to form masses of porous rocks, the pores being due to the escape of gas. When excessively light and porous the rock is called pumice.

With many minor differences, this description will hold good for most of the great volcanoes of the earth. Most of these show a cone built up of a combination of fragmentary materials and lava, and where the cone reaches a great size the lava rarely wells out of the central crater, mostly making its escape from lateral vents or fissures. As the result of the accumulation of volcanic materials, enormous mountains are built up, often extending far above the snow-line. In this case a prominent symptom of approaching activity is the melting of the snow of the summit, which may give rise to floods more disastrous in their effects than the actual eruption. Of this Cotopaxi, which reaches the height of 19,480 feet, is an example.

In addition, however, to this usual type of volcanic cone, two other less common forms are recognised. One is the cone composed exclusively of fragmentary materials, with no lava. Such cones are usually small. A good example is Monte Nuovo, near Naples, which was produced in two days in 1538. Such cones are subject to rapid modification, their loose constituent elements continually tending to slide. Their slopes are usually very steep. This type of cone is commoner as a parasitic cone—that is, as a secondary out-

growth from a volcanic mountain, than as an independent mountain. The summits of Vesuvius, Etna and Stromboli, for example, show such cones of fragmentary material.

The third type, also somewhat rare, consists of those

Fig. 46. The Volcanoes of Hawaii.

mountains of volcanic origin in which fragmentary material is entirely absent, the whole mountain consisting of solidified lava. The best-known examples are found in the Sandwich Islands, and mountains so produced are not conical, for they show peculiarly gentle slopes. As an example we may take

Mauna Loa. It is the highest of the four volcanoes which have united to build up the island of Hawaii. The whole island appears to be built of volcanic materials, and it rises from an ocean about 16,000 feet deep. Mauna Loa reaches a height of about 14,000 feet above sea-level, so that the material poured out by the volcanoes forms a pile some 30,000 feet high. The slopes are very gentle, rarely reaching an angle of 7°, while those of a cinder cone may reach an angle of 30° or more, Vesuvius having a slope of 35° near its summit. At the summit lies a crater which is 3 miles long, 2 miles wide, and some 1,000 feet deep. When the volcano is not active this floor is hard enough to walk upon, though it is still hot. The floor is not level, for steep-sided hollows occur over its surface. In the adjacent crater of Kilauea such depressions are occupied by lakes of boiling lava, but no permanent lava lakes occur in the Mauna Loa crater. Eruptions are, nevertheless, frequent. They differ markedly from the Vesuvius type in that explosions do not take place, the gaseous emanations are small in quantity, earthquake shocks are infrequent, and, as already stated, the ejection of fragmentary material does not occur, or only to a very slight extent. The lava seems to slowly boil up in the crater, in a fashion which has been compared to the boiling over of a saucepan filled with milk. Sometimes it flows quietly over the lip of the crater and so escapes; at other times it finds a way out by a lateral outlet. It is excessively fluid, the lava streams tumbling over cliffs in falls, and behaving generally like fast-flowing glaciers. The streams are very wide, and sometimes flow for 50 miles.

A remarkable phenomenon which occurs at the point where the lava streams emerge is the occurrence of lava fountains, the liquid rock leaping up into the air to a height sometimes of 300 feet, like the water of a geyser. This seems to be due to the amount of gas which is entangled with the lava. The fluid lava allows it to escape quietly, while in the explosive type of eruption exemplified in Vesuvius this gas is only liberated by a series of explosions which blows the partially solidified rock into dust. The two types of eruption are thus very markedly contrasted.

Distribution of Volcanoes.—The accompanying map shows the important points in regard to the distribution of volcanoes. Those active at the present time are estimated

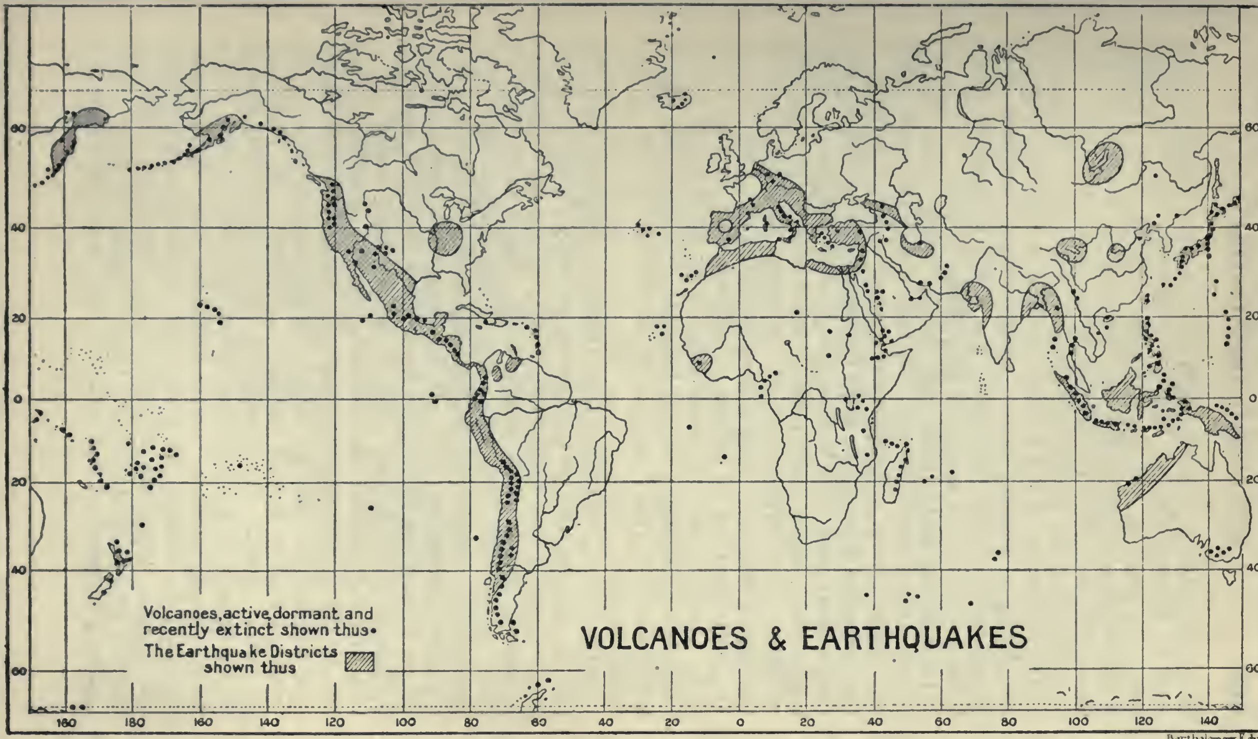

Fig. 47. Distribution of Volcanoes.

to be 300–400 in number, and, as the map indicates, they tend to occur in belts. Their arrangement and their abundance in regions where earth movements have recently occurred lead to the conclusion that they are associated with these, but as a consequence and not as a cause. They seem to result from the great movements of folding and fracturing, and active vents at the present time lie in regions subjected to folding in Tertiary times, while those which have been long extinct (fossil volcanoes) are found in regions where folding occurred in long-past geological epochs.

In more detail we may note that not only is the Pacific ringed with active volcanoes, but that within the ocean itself are many others. The greatest seat of volcanic activity at the present day is in the great mountain chains which circle that ocean, and which face great ocean depths. These regions are areas where earth movements have recently occurred. Similarly a zone of vulcanism in Europe marks the region where Tertiary folding occurred (*cf.* Figs. 13 and 47), and this zone of folding is followed into Asia by a belt of fire, and is continued westward into the New World by the volcanoes of Mexico and the Antilles. Similarly the line of the Great Rift valley (*cf.* p. 49) is marked also by a band of volcanoes.

Solfataras, Geysers and Thermal Springs.—At the present day we find on the surface not only volcanoes in all stages of activity, but others in which only the last symptoms of activity remain, and others, again, which have not only been extinct for long ages, but whose cones have been enormously modified by the ordinary forces of erosion. We are thus enabled to follow all the stages of a volcano's life. When its activity has so far diminished that it is unable to discharge either molten rock or fragmentary matter, it is said to have reached the *solfatara* stage. A solfatara constantly gives off gaseous emanations, sulphuretted hydrogen and sulphurous vapours being frequent. Vulcano in the Lipari islands is a good example. Geysers, also limited to regions of recent volcanic activity, form a somewhat similar phenomenon. A geyser is an intermittent hot spring, whose water usually contains much dissolved gas. Geysers are abundant in Iceland, as well as in the Yellowstone region. The geyser apparatus consists of a channel of unknown depths, round whose mouth there is either a basin, or a mound perforated at the summit. The basin or the mound

is composed of matter deposited from the water, usually consisting of silica. At intervals, which are sometimes regular and elsewhere quite irregular, a column of water mingled with steam is shot out from the orifice, sometimes to a great height. The ejecting force is steam, and it is believed that water at a particular region in the geyser tube is subjected to the action of heat. After this heating has gone on for a longer or shorter period, the elastic force of the steam generated is great enough to force out the superincumbent mass of water, which appears at the surface in a fountain mingled with the steam produced by the sudden release of pressure.

With gradually diminishing activity such manifestations become less and less marked. Among the minor phenomena which are obvious in such cases are mud volcanoes, where gas-containing water wells up from the ground and converts the superincumbent earthy matter into mud, so that a miniature cone is formed. Another indication of dying volcanic activity is the presence of what are called mofettes, that is, exhalations of carbonic acid, as in the Death Gulch in the Yellowstone, and the well-known grotto near Naples. Finally, when all other signs have disappeared, thermal springs may remain to tell of past volcanic activity. Thus the thermal springs of Vichy are associated with the extinct volcanoes of the Auvergne. Not all hot springs, however, are directly associated with volcanic activity. In some cases the heat of the water seems to be due merely to the depth from which the water has come.

Briefly, *active* volcanoes eject gases, steam and either fragmentary matter or lava or both together. As activity wanes, the eruptive force only permits the discharge of gases or of water, and the phenomena of solfataras, geysers, thermal springs, etc., arise.

Effects of Denudation on Volcanic Cones.—As volcanic activity diminishes the cones are acted upon by wind, rain, frost, running water, and so forth. The loose and unconsolidated materials are worn away, while the more solid parts, and especially the solidified lava, offer more resistance to the denuding forces. It thus often happens that in the course of time a well-marked "inversion of relief" occurs. The summit cone, generally consisting of débris, is first washed away, while the lava which once occupied the crater and plugged the vent after the last

eruption remains as a hill when the crater walls disappear. Similarly, lava streams often flow along river valleys, and as the solidified stream may be harder than the walls of the original valley, in the course of ages the original valley may be marked by a winding ridge of volcanic rock, much as a winding œsar marks the position of an earlier valley. Again, lava is often injected between beds of sedimentary rock, and in the course of time the sedimentary rock is worn away, and the lava remains as a hill of very striking relief. Such isolated hills, though primarily volcanic, owe their form to the ordinary agents of erosion, and have always attracted man, especially in warlike days, as suitable sites for citadels. On such bosses of volcanic rock the castles of Edinburgh and Stirling stand, and round the base of the citadel the town sprang up in each case; such conditions are exceedingly common, though the town does not persist unless the site offers some other advantages in addition to the possibility of defence.

Earthquakes and their Origin.—We have just seen that volcanoes are associated with regions of active earth movements, and may therefore be regarded as one of the indications that such movements are going on. Still another symptom is the occurrence of earthquakes, which are tremblings of the earth due to fracture and movement of rocks. The surface of the earth owes its present form largely to movements which were inaugurated in Tertiary times, and the frequency alike of earthquakes and of volcanic activity at the present day are indications that those great movements are still continuing.

Earthquakes, like volcanoes, are distributed over those regions of the globe where recent folding and fracture have taken place (Fig. 47), but there is not necessarily a close connection between the two phenomena. In other words, earthquakes are not necessarily, as was once supposed, closely related to volcanic activity; rather are both due to a common cause.

Earthquakes are of such great human importance that they are studied with great care, the science being called seismology. The tremors are measured on very delicate instruments called seismometers, which are set up in many observatories over the globe. By the study of the records of a great number of these instruments, it becomes clear that every earthquake shock has a zone of maximum inten-

sity, and diminishes in all directions as one travels away from this zone. This zone is called the epicentral zone, and is supposed to lie above the region in the crust where the actual fracture giving rise to the tremor has occurred. From it the waves are propagated in all directions through the surrounding rocks. Lines drawn to connect points where a given earthquake wave is felt at the same time are called coseismic lines.

Earthquakes have often very marked human effects, leading to great destruction of life and of buildings, to alterations of drainage, and so forth. Not infrequently also they produce obvious dislocations at the surface. Thus in Japan the earthquake of 1891 led to the opening in the ground of a fissure traceable for over 40 miles, one side of the fissure sinking 2–20 feet below the other; in India, in 1819, associated with earthquake shocks there was a subsidence of a large area in the delta of the Indus river below sea-level, while an adjacent region rose about 10 feet. Such phenomena are frequent, and, taken in conjunction with other evidence, they lead to the conclusion that earthquakes are associated especially with the fracture of rocks, forming so-called faults. We have already indicated (p. 43) what important effects such dislocations may have upon the surface, though the most important results are due less to the direct effect of the dislocation than to subsequent denudation. In the United States of America the "fall-line" (*cf.* p. 35) is due to a great dislocation which has brought the coastal plain down, and so protected its Tertiary beds from denudation; while the piedmont plateau is the upcast side of the fault, and here old, relatively infertile rocks have been exposed, and make the region one of forest and hill pasture, as compared with the fertile agricultural plain below. The line of faulting, the fall-line proper, gives the streams here rapids and falls, and thus at once limits navigation and yields water-power. The double fault which has let down the Midland valley of Scotland (p. 49) has had as great importance in the development of that country.

Faults frequently occur in regions where folding has been going on, but nevertheless there is a distinction between regions where they predominate and those where folding predominates. Faulting on the large scale tends to occur in such regions as the Vosges (see Fig. 16), the Midland valley of Scotland, East Africa, etc.; that is, in regions of

old rocks (*cf.* p. 43). On the other hand, folding tends to occur in regions of younger rocks and of very high relief, *e. g.* the Alps, Himalayas, etc.

Evidences of Elevation and Depression.—As just stated, we often find associated with earthquakes alterations of level. Such alterations are often regarded as caused by the earthquake, though it seems more accurate to say that they are merely the manifestation of the fracturing of rocks which give rise to the earthquake. But even when earthquakes do not produce obvious changes of level they are of interest as manifestations of the internal forces which are continually modifying the crust. Another series of phenomena—the evidences of slight and slow changes of level—are similarly of interest, in that they help to draw attention to these forces. That the relative position of sea and land is continually undergoing change we know, for, as we have seen, the peculiarities of the surface at the present day can be explained upon no other hypothesis. But these changes for the most part take place very slowly, and the actual process cannot be directly observed. The so-called evidences of elevation and subsidence, therefore, though the actual movements indicated by them are insignificant in the extreme, are of importance because, no less than volcanoes and earthquakes, they serve to direct our attention to the greater phenomenon.

The evidence for relative changes in position of sea and land can be readily summarised. These are proved by the evidence of human buildings, etc. The well-known temple of Jupiter Serapis in the Bay of Naples affords evidence both of elevation and subsidence in this region, while similarly in the island of Crete it has been shown that while remains of old docks occur twenty-seven feet above present sea-level, in other parts of the island ancient buildings are submerged beneath the water. In Scandinavia it has been shown by actual measurement that most of the coast-line is rising, at a rate of about two and a half feet per century, while the southern end of the peninsula is sinking. Even more striking is the evidence of raised beaches (p. 34), so common in Scotland, Scandinavia and elsewhere. Again, the remains of old forests are sometimes found on shores near low-tide mark, in positions where trees could not grow now. Such a submerged forest is well shown at Leasowe on the coast of Cheshire, where the stumps of

the old trees are still in position, and proves that the region has subsided. Again, the fact that river valleys are often prolonged over the continental shelf (*cf.* p. 19) far from the present shore is evidence of subsidence, as is also the condition described in New Guinea (see Fig. 12), where the land remains swampy, despite the enormous amount of débris brought down by the rivers.

REFERENCES TO SECTION III

The general works on Physical Geography and Geology mentioned at the end of Section II should be consulted for the subject matter of this section also. Mackinder's *Britain and British Seas* (Oxford, Second Edition, 1907) gives an account of the origin of British rivers, and in Gregory, *Geography, Structural, Physical and Comparative* (1908), there is an interesting account of coast-lines as well as of some other points discussed in this section. For glaciers and the work of ice, reference should be made to Geikie, *Great Ice Age* (Third Edition, 1894) ; Penck u. Brückner, *Die Alpen im Eiszeitalter* (Leipzig, 1909) ; Hobbs, *Characteristics o Existing Glaciers* (New York, 1911).

SECTION IV—MATHEMATICAL GEOGRAPHY

CHAPTER XI

THE SHAPE, SIZE AND MOVEMENTS OF THE EARTH

Form and Size of the Earth.—Movements of Rotation and Revolution.—Shape of the Earth's Orbit.—The Equation of Time.—The Moon, its Phases and Characters.—Eclipses.—Terrestrial Magnetism.

Form of the Earth.—That the earth is approximately spherical is a notion to which we have been accustomed from childhood, so that its apparent contradiction of the facts of experience presents no difficulty to us. It is, however, worth notice that, despite the long period during which the belief that it was flat lingered, the rotundity was recognised by the Greeks at a very early date. They realised, on astronomical grounds, that the apparent flatness must be deceptive, although the familiar ship argument was, it would seem, not known to them. They laid special stress on the fact that when a man travels northwards, stars which were originally in his northern horizon seem to travel over to the south, while those which were originally visible in the southern horizon disappear altogether; and they saw that this must mean that the earth is round (Fig. 48). At an early age also it was recognised that the fact that the shadow cast by the earth upon sun or moon during an eclipse is always circular must mean that the earth is round, for only a sphere can always cast a circular shadow. When, at a very much later stage, the view of the earth's rotundity passed from being a bold speculation of the philosopher into a fact related in a thousand ways to daily life, other forms of proof were brought forward, notably the familiar one that in a ship sailing away from an observer the hull disappears first, the top of the masts last, while in one approaching the observer the conditions are reversed.

Size of the Earth.—If we seek to pass, however, from such generalised proofs that the earth is, roughly, spherical in form to the attempt to obtain a conception of its true shape, we find the matter much more difficult. The subject is closely bound up with methods of determining the size of the earth, and this subject we may proceed to consider next. The earliest known experiment on the subject was performed by Eratosthenes (about 200 B.C.), and his method in essence is that still employed. Eratosthenes knew how to obtain the altitude of the sun at midday by means of a long vertical pole (see Fig. 57). Working at Alexandria, he obtained a figure for this altitude at the date of the summer solstice. Further, he knew that at the same time the sun was in the zenith, *i.e.* directly overhead, at Syene (Assuan), a town which he believed to be due south of Alexandria, the distance to which he knew. The diagram (Fig. 49) shows the simple process of reasoning employed. A and B represent the two places, separated along the curved surface of the earth by a distance indicated by the line AB, which is the arc of a circle of which C is the centre. If radii are drawn from the arc to the centre of the circle, then we have at C the angle subtended by the arc, whose length is known. At A the sun is vertical, so that AR represents the direction in which it appears to be. Its deviation from the vertical at B is represented by the

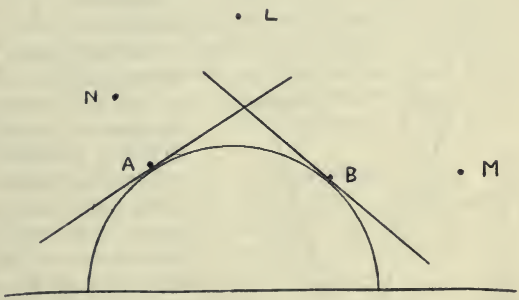

Fig. 48. Diagram to show how the changed position of the stars to an observer travelling north or south proves the rotundity of the earth.

To an observer at A the two stars L and N are both visible, L being in the south of the sky. If the observer travels southwards over the surface to B he finds that N gradually sinks below his horizon, while L passes from the south to the north and a new star, M, comes into view in the south.

angle TSB, where BT is a prolongation of the radius CB, and BS is a line drawn in the direction in which the sun appears to be to the observer at B. Now it can easily be shown by Euclid that the angle at C is equal to the angle TBS, for the lines AR and BS are parallel, and the angle TBS is the zenith distance of the sun at B, and is obtained by deducting the altitude of the sun at B from 90°. We have thus a simple ratio as follows: $\angle C : 360° = AB : x$, 360° being the angle corresponding to the whole circumference of the circle, and $\angle C = \angle TBS$. From this equation x, the circumference of the earth, is readily found.

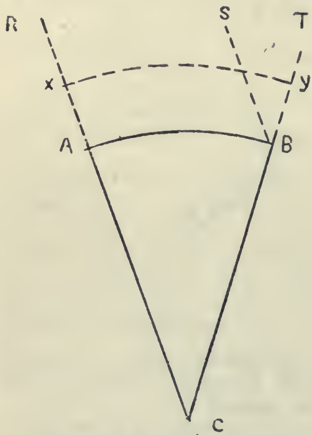

Fig. 49. Diagram to illustrate Eratosthenes' experiment. (For explanation see text.)

Eratosthenes' results were surprisingly accurate, all things considered. Long centuries afterwards many detailed measurements of arcs of latitude were made, with ever increasing accuracy. At first these were made on the assumption that a degree of latitude has precisely the same length in all parts of the globe. Actual measurements soon proved this to be incorrect, and Newton showed on theoretical grounds that it could not be true. He pointed out that, owing to the action of centrifugal force, if the earth were a true sphere, then particles at the pole, if free to move, would roll down towards the equator. As this does not occur, the earth cannot be a true sphere, but must bulge at the equator. He was led to this train of reasoning by an observation of the astronomer Richer, who found that a very carefully regulated clock when transported from Paris to Cayenne lost time, and had to have its pendulum shortened before its indications could be relied upon. Now with a pendulum of given length the time of swing depends upon proximity to the centre of the earth. Thus a pendulum clock which keeps true time at sea-level will lose on the top of a mountain, because it is there further away

from the centre of the earth. Thus Richer's observation suggested the presence of a bulging at the equator (Cayenne being in lat. 5° N.), this making a place there further away from the centre of the earth than one at the same level above the sea in higher latitudes.

An obvious method of confirming, or otherwise, Newton's view was to measure accurately the length of a degree of latitude in the Arctic area and also near the equator. This was done, and showed that the degree is slightly longer near the Arctic than towards the equator, the difference being some 3,600 feet when a degree in lat. 0° is compared with one in lat. 80°. In other words, the curvature is greater nearer the equator than at the poles, or the earth is flattened at the poles. This last conclusion is obvious if we suppose that XY in Fig. 49 represents an arc of latitude in the polar regions and AB one near the equator. Because the distance XY is greater than the distance AB, XY is necessarily flatter.

As to the actual figures, the circumference of the earth is about 25,000 miles, or 40,000 kilometres. If we express these facts in terms of human locomotion, we may note that a moderately fast express train (running at about 40 miles an hour) would carry a man round the world in less than four weeks, if it could run continuously. Similarly a steamship, travelling at 20 knots an hour, if a complete sea-route were possible, would take him round in 45 days (de Martonne). The deviation from the perfect sphere shown by the globe would not make much difference to this voyage. for the difference between the greatest circumference and the shortest is only some 42 miles—only an hour's difference in our express train.

Owing to the flattening at the poles just described, the earth is commonly said to be an oblate spheroid. Further detailed observations, however, seem to show that this description is inaccurate. The earth is not a true spheroid, but is slightly irregular in shape. To say that it is an oblate spheroid is, however, near enough for geographical purposes.

Rotation of the Earth.—It was long after the rotundity of the earth had been proved that its two movements of rotation and revolution were discovered. The first, the fact that it rotates upon its own axis in a period of twenty-four hours, is of great importance not only in that it produces

the alternation of day and night, but also in that it helps us to fix the position of points upon the surface. That the earth rotates can be proved in various ways, notably by the fact that a body dropped from the top of a high tower undergoes a slight deviation before it reaches the ground, because objects at such an elevation are rotating notably faster than those at sea-level, and as they fall tend to keep their initial velocity, and so do not "fall straight." Another proof is found in the fact that a carefully swung pendulum of great length shows a gradual change in the direction of swing which can only be due to the rotation of the earth. This experiment was first performed by Foucault at Paris.

As the earth rotates upon itself two points on its surface remain immovable, these being the places where the prolonged axis cuts the surface. These points are the poles. A plane drawn through the centre of the earth at right angles to the axis forms at the surface a circle lying midway between the poles; this circle is the equator. Other planes drawn through the centre along the line of the axis form at the surface circles which cut the equator at right angles; these are meridians of longitude. In each of the two hemispheres into which the equator divides the globe circles are drawn parallel to the equator, these forming parallels of latitude. The parallels of latitude are numbered from the equator to the poles, 0° to 90° in each hemisphere; the meridians are measured from an arbitrary zero meridian, which is Greenwich for British people; other nations often select their own capitals, *e.g.* Paris, Washington, etc. From the chosen zero meridian we measure 180° E. or W., the line 180° being exactly opposite 0°.

Let us suppose now that the great circle which passes through the poles and forms at the surface of the globe a meridian of longitude is prolonged into the sky indefinitely; it forms there a celestial meridian, whose intersection with the horizon of any observer marks the north and south points of the horizon for that observer (see Fig. 58). As the earth turns upon itself, it is obvious that all the heavenly bodies, which may be regarded as lying inside an infinite sphere which surrounds the globe, will seem to the observer to approach the meridian, pass it, and then move away in the opposite direction. As the earth moves some of these heavenly bodies pass completely out of our range of vision, when they are said to set. In most, though not in all lati-

tudes at all seasons the sun is such a body. Other bodies, such as the sun itself in the summer of high latitudes, and the stars called circumpolar stars (see Fig. 55), never set, and therefore necessarily cross the meridian twice, as they ascend and as they descend in their circular course. We thus arrive at the notion of the *altitude* of a heavenly body, a subject which we shall have to consider in more detail later.

Let us turn for a moment to the sun in the latitudes in which he sets at all seasons. The earth rotates from west to east, and therefore the sun appears to rise in the east, to climb the sky steadily to his maximum altitude, and then to descend westwards. Obviously, when he has reached the highest point of his daily course he has completed half his course—this is the period we call noon. If we place an upright stick in an open piece of ground on a sunny day, we shall find that the shadow of the stick diminishes from dawn till noon, when it reaches its minimum, and then increases again till sunset. In the northern hemisphere the sun at noon is due south, and the shortest shadow points north. Thus the noontide shadow traces on the ground a minute arc of the meridian, and enables us to define north and south. In point of fact, the north is usually obtained by a compass, but, as we shall see later in treating of terrestrial magnetism, the point to which the magnetic needle points is not the true north; it is not the direction obtained from the shadow experiment.

At the equinoxes the sun gives us the two other chief points of the compass, for he rises in the east and sets in the west.

Not only does the rotation of the earth thus enable us to fix the points of the compass, it gives us also a means of measuring time. The earth rotates in twenty-four hours, returning at the end of that period to the point from which it started (but see p. 161). It has thus rotated through 360° in twenty-four hours, and therefore through 15° of longitude in one hour, or 1° in four minutes. Thus we can regard four minutes of time as the equivalent of 1° of longitude. Owing to the direction of rotation, places to the east see the sun sooner than those to the west at the rate of four minutes to 1°, and thus time is later to the east of a given place and earlier to the west.

Now while isolated communities may without difficulty

use local time, obtaining the daily noon by an altitude observation of the sun, modern communities linked together in a thousand ways can obviously not do this. An arrangement must, therefore, be made whereby certain areas have a common standard of time, which does not vary too much from the true time. The most logical arrangement is that adopted by the United States, with their enormous extension in longitude. Here a system of standard time has been adopted by the railway companies. The country is divided into belts 15°, *i. e.* one hour, wide, and all places in the belt use the time of the central meridian, time changing by one hour as we pass from one belt to the next. Thus we have Eastern time, which is that of Philadelphia, lat. 75° W. of Greenwich and places to the east of it; Central time, which is that of St. Louis, lat. 90° W., and a belt of places on each side of it; Mountain time, which is that of Denver, lat. 105° W., and places to east and west of it; Pacific time, which is the true time of lat. 120° W., and is the time standard of places to east and west of it, within a determined area.

In the Old World the matter is complicated by the fact that countries frequently, though not always, prefer to keep the same time within their political frontiers. Thus Great Britain keeps Greenwich time, which is local time only over a relatively small part of the area, most of the country lying to the west of this meridian. Ireland keeps Dublin time, because its most westerly part has noon more than forty minutes after Greenwich. France now keeps Greenwich time, while Switzerland, together with Germany, Italy, Austria-Hungary and Denmark, take Central European time, which corresponds to lat. 15° E., and is one hour fast by Greenwich clocks. But, as the map shows, parts of France are east of parts of Switzerland, and therefore a traveller going from the town of Geneva along the southern bank of the lake has to put his watch *back* an hour, although he is going *east*, where time ought to be fast. Similarly, though time is the same along any meridian, if he cross the lake from north to south he must put his watch *back* also. Such little puzzles are worth notice, because they serve to show that the clock time of any particular place is fixed by a convention, and not by the sun.

Eastern Europe takes its time from lat. 30° E.; that is, its clocks are two hours fast by Greenwich time. The

countries falling under this convention are Russia, Bulgaria and Turkey. The other time meridians can be obtained from a nautical almanack.

Revolution of the Earth.—While the earth's first movement, that of rotation, gives us the phenomenon of day and night, its second, that of revolution round the sun, gives us the supremely important phenomenon of the seasons. The existence of this movement is a deduction, drawn comparatively late in time, from a whole series of phenomena which had been observed from the dawn of history. It is, therefore, not remarkable that our language should bear the trace of earlier periods before the movement was understood. Nor is there any harm in speaking of the "movements of the sun," if we realise that these are apparent and are due to the earth's revolution.

Let us first summarise generally the appearances presented by the path of the sun throughout the year to an observer situated at any station in the northern hemisphere. If we begin our observations on March 21, we shall find then that the sun rises exactly in the east, ascends the sky till at noon he rises to his highest point and stands in the south, then descends steadily to sink into the west. Day and night are of equal length. Thereafter we notice that the sun shows a northward shift; every day he rises a little further to the north of east, every night he sinks to the north of west; every noon he is a little higher in the sky, so that a noontide shadow diminishes in length. This continues till the summer solstice, June 21, when the days, which have been steadily lengthening, reach their maximum. Thereafter the sun begins to creep southwards. Every noontide the shadows are a little longer; every dawn occurs a little further to the south. This continues, till on September 23 the conditions are similar to those on March 21, that is, days and nights are of equal length, sunrise is in the east, sunset in the west. These two dates are, therefore, the equinoxes, because day and night are of equal length. After September 23 the days grow steadily shorter, the sunrise takes place further and further to the south, so that necessarily the sun's path across the heavens is shorter, and the noontide shadow is long, because even at his highest point he is relatively low in the sky. These conditions reach their maximum at the winter solstice, December 21, so called because the sun then seems to turn

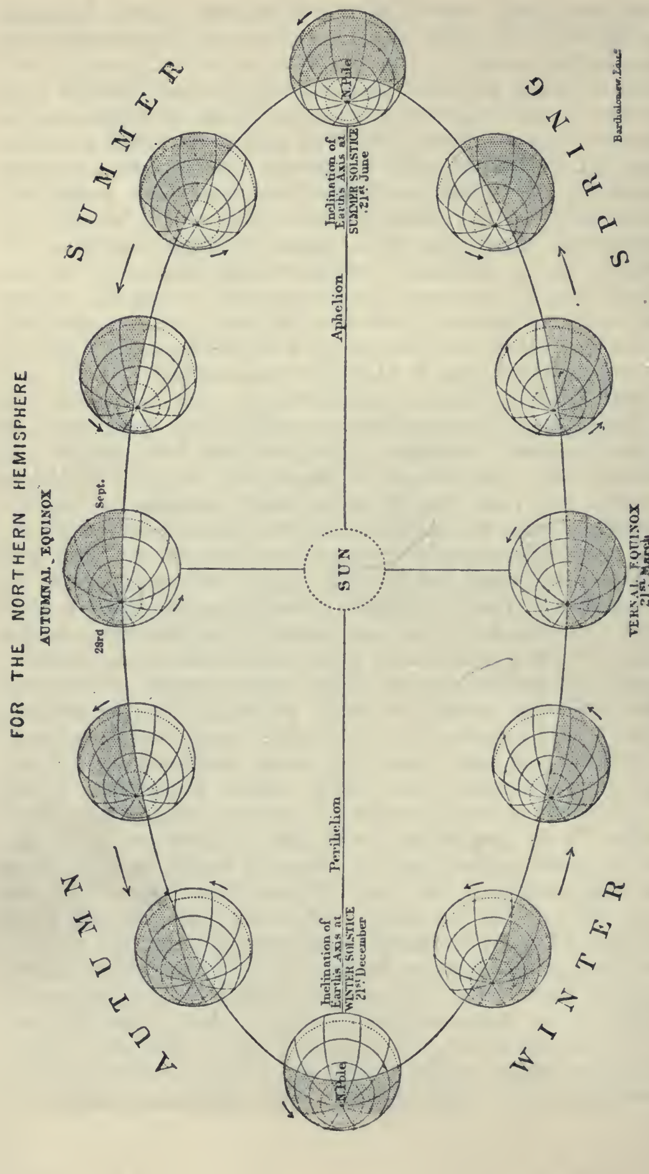

Fig. 50. Diagram to illustrate the Causation of the Seasons.

and reascend the heavens, just as at the summer solstice he seemed to turn to descend the heavens. After the winter solstice the noon sun appears higher and higher in the heavens, and the short days grow longer, till at the spring equinox they are equal to the nights, and the cycle recommences. Now, before the dawn, the different regions of the sky can be recognised by the constellations which adorn them. It is easy to observe that the part of the sky at which the sun rises in, say, December, is not the same as that where it rises in, say, March, for the constellations in which it rises are different in the two cases. It is therefore convenient to speak of the sun as being "in" one or other of the signs of the zodiac. Thus on March 21 the sun enters Aries and spring begins; on June 21 he enters Cancer and summer begins; on September 23, when he enters Libra, autumn begins; and as he enters Capricornus on December 21 winter begins.

Let us suppose our observer to be placed at the equator on March 21. At noon on that date a pole placed upright in the ground will cast no shadow. In other words, the sun then appears to be directly overhead, or in the zenith, the zenith being defined as the direction in which the extension skywards of a plumb-line points. Let our observer travel slowly northwards, setting up his pole at increasing latitudes north of the equator. He will get the condition of no noon shadow, or sun in the zenith, at successive stations on certain fixed dates, till he comes to a point in lat. 23½° N. This marks the limit of the area north of the equator within which no noon shadow occurs, and this condition is satisfied on one day of the year only, that day being June 21, or the summer solstice. As the sun enters the constellation of Cancer here, and as the line is his turning-point, it is called the Tropic of Cancer, and the similar line to the south of the equator is the Tropic of Capricorn. Within the area marked out between lat. 23½° N. and 23½° S. the sun is overhead at least on one day in the year, further north and further south it is never in the zenith at any season.

The apparent path of the sun in the heavens, as marked out in this way, is called the Ecliptic, and the earth's axis is inclined at an angle of 66½° to the plane of the ecliptic, or 23½° to the plane of the equator.

Let us now consider a little more in detail the length of

the day in the different latitudes at the different seasons. If we begin with the spring equinox of the northern hemisphere (March 21), we know that then the sun is in the zenith over the equator, and the circle of illumination passes through the poles, so that half the globe at any one time is plunged in darkness and half is in light (see Fig. 50). Therefore over the whole of the globe the days and nights are of equal length. Now let us turn to the summer solstice. At this time the rays of the sun form an angle of 23½° with the equator, with the result that the circle of illumination no longer passes through the poles, but makes an angle of 23½° with the line of the poles. Thus, as the figure shows, the South Pole is permanently in darkness, while the North Pole has perpetual day. At the time of the summer solstice the whole area between the pole and lat. 66½° N. is in perpetual light, *i. e.* within this region the sun does not set. Similarly on this date the *whole* of the area between lat. 66½° S. and the South Pole never sees the sun during at least twenty-four hours. At the equator, as the diagram shows, the days and nights are of equal length, as they were at the equinox. The intermediate latitudes have intermediate lengths of day and night; and at the summer solstice the length of day in different latitudes is as follows—

Within 66½° N.	24 hrs.	0 min.
At 50° N.	16 ,,	18 ,,
At 40° N.	14 ,,	52 ,,
At 30° N.	13 ,,	56 ,,
At 20° N.	13 ,,	12 ,,
At the equator	12 ,,	0 ,,
At 20° S.	10 ,,	48 ,,
At 30° S.	10 ,,	4 ,,
At 40° S.	9 ,,	8 ,,
At 50° S.	7 ,,	42 ,,
Within 66½° S.	0 ,,	0 ,,

Thus at the summer solstice the length of day steadily diminishes from 24 hours within 66½° N. through 12 hours at the equator to 0 hours within 66½° S., and at the winter solstice the conditions are reversed, the area within 66½° N. being in darkness and that within 66½° S. in permanent day. The lines 66½° N. and 66½ S., which mark the areas within which on at least one day in the year the

sun never sets in summer and never rises in winter, are called the Arctic and Antarctic Circles respectively. At the actual Poles the day and night are respectively six months long, at the equator throughout the year the days and nights are 12 hours long; in the intermediate latitudes we have conditions which change with the seasons.

Twilight.—We have spoken above as if darkness commenced with sunset and ceased at sunrise. This is, of course, not the case, for after the sun has passed below the horizon a certain amount of light lingers in the sky, and a dim twilight similarly appears before the dawn, this being due to the reflection of light from clouds, vapour and floating particles in the upper regions of the atmosphere. Now it has been proved that this twilight lasts after sunset till the sun is 18° below the horizon, and begins before dawn when he has ascended within the same distance of it. Obviously, therefore, the steeper his course the shorter time will it take him to pass through these 18°, and the shorter will the twilight be. Conversely, the more slanting the course the longer will the period last. Thus in tropical latitudes twilight is always short, and darkness follows rapidly on the setting of the sun. On the other hand, in high latitudes it lasts long, and may endure the whole night. In this case though the sun sets there is never perfect darkness. A very simple rule enables us to calculate the number of nights in the year when there is all-night twilight in any latitude, but to do this we must first consider the meaning of the term *declination.* The declination of a heavenly body is defined as its distance from the equator measured on the arc of a Great Circle passing through the body and the pole.

Let us note first the meaning of a Great Circle. If a sphere be cut through by a plane passing through its centre, then the intersection of the plane with the surface of the sphere will be a circle, and all such circles will have the same size. These circles are Great Circles, and it is obvious that all meridians are Great Circles, while of the parallels of latitude only the equator is a great circle, the others being small circles. If now we take a plane which passes through the centre of the globe, and continue this plane till it meets the sun, then the angle which this plane makes with the plane of the equator at the centre of the earth will give the declination of the sun. Thus

the maximum declination of the sun will be $23\frac{1}{2}°$ N. or S. of the equator. Now the rule for the duration of twilight is that if at any place the latitude plus the sun's declination on any night of the year is not less than 72° and not greater than 90°, then that place will have twilight all night through. For example, let us take London, which has a latitude of $51\frac{1}{2}°$. The maximum declination of the sun is $23\frac{1}{2}°$, and this occurs at the summer solstice, $51\frac{1}{2}° + 23\frac{1}{2}° = 75°$, so that obviously London has twilight all night long at the summer solstice. But as $51\frac{1}{2}° + 20\frac{1}{2}° = 72°$, it is obvious that so soon as the sun's declination exceeds $20\frac{1}{2}°$ there will be twilight all night through at London, and this condition will last after the summer solstice so long as the declination remains in excess of this figure. Now from a nautical almanack we can obtain the sun's declination for every day of the year, and this will show us that for two full months in summer London has no true night, for twilight lasts all night from the latter part of May to the latter part of July.

As the latitude increases as we travel northwards, while the sun's declination remains the same, it is clear that the number of nights with continuous twilight must increase as we travel to the north and diminish as we journey southward towards the equator. Any place within 48° lat. will have at least one night with continuous twilight, because $48\frac{1}{2}°+23\frac{1}{2}°=72°$. Places within $66\frac{1}{2}°$ have, of course, some nights not of continuous twilight but of continuous daylight.

Shape of the Earth's Orbit.—The diagram (Fig. 51) indicates generally the shape of the earth's orbit, which is an ellipse, the sun lying at one of the foci of the ellipse. As the diagram shows, the earth is in consequence at one time near the sun, or in perihelion, and at another time further away from it, or in aphelion. The sun is in perihelion in the northern autumn and winter and in aphelion in the northern spring and summer. It would seem, therefore, that during the two first periods the globe should receive more heat than during the other two. This, however, is not the case, for the angular velocity of the earth along its path is not the same. During the period when it is in perihelion it moves faster than when it is in aphelion, and the greater velocity exactly compensates for the greater proximity, so that the amounts of heat

received in passing from M to S is approximately the same as that received while passing from S to M. Nevertheless, the fact that the sun is in perihelion during the southern summer seems to make the summer there hotter than in the corresponding latitudes to the north, though what the southern summer gains in intensity it loses in duration, for the seasons are of slightly unequal length

It is interesting to note that the solstices do not correspond with the times when the sun is furthest away and nearest to the earth respectively. The position alike of the solstices and equinoxes varies slightly, this being called the precession of the equinoxes. Variation takes place to the extent of about 62° per annum, and this induces disturbances of the thermal equilibrium between the two hemispheres which have been regarded as a cause of the Ice Age.

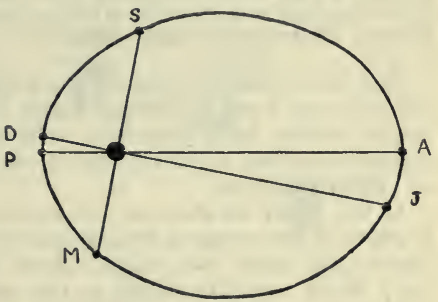

Fig. 51. The Earth's Orbit.

A, aphelion ; P, perihelion ; D, position of the earth at the December solstice, and J at the June solstice, S at the September equinox, and M at the March one. Summer in the northern hemisphere lasts while the earth moves from J to S, autumn while it travels from S to D, winter from D to M, and spring from M to J. Note that during the northern autumn and winter the earth is in perihelion ; this is the southern spring and summer. Note also that the line of the equinoxes does not coincide with that of perihelion and aphelion.

Equation of Time.—The four seasons together last about 365¼ days, or one year. Thus in a year the earth comes back to the point from which it started, and its movement of translation gives us a measure of time, the extra hours being allowed for by an intercalated day in leap year. While the movement of rotation, then, gives us the interval of twenty-four hours or a day, the movement of revolution gives us the year. We must next consider the effect of the two movements in combination. The earth turns upon its own axis in twenty-four hours, so that we might suppose that the interval between two meridian passages of the sun at any locality should be exactly this period. But during the time which the earth has taken to rotate it has also moved a perceptible distance in its orbit. As the earth takes 365¼ days to move through 360°, in one day, or period of 24 hours, it has moved nearly one degree, therefore the

period between two successive meridian passages of the sun should be 24 hours and nearly 4 minutes, because the earth has to move through this degree, which takes it 4 minutes. But this calculation is based upon the supposition that the earth moves uniformly round the sun, and we have just seen that it moves now fast and now slow. Thus we arrive at the conception of the equation of time, the correction which must be applied to convert the actual length of time between two meridian passages of the sun into a mean solar day, or period of twenty-four hours exactly. The deviation of the actual solar day from the mean solar day is not only due to the unequal motion of the earth in her orbit, it is also due to the inclination of the ecliptic to the equator, but the two elements are combined to form the equation of time. The most obvious use of this equation of time, which is furnished by a nautical almanack, is that it must be applied as a correction to the readings of a sun-dial; it is also, however, of importance in many calculations.

The Moon.—The moon is the satellite of the earth and accompanies it on its journey round the sun. It is a very much smaller body than the earth, having a diameter of rather more than a quarter, and a volume of one forty-ninth of that of the earth.

If the moon be observed on successive nights it will be found that she moves eastward among the stars, rising about 50 minutes later each night. After rather more than 27 days she is found to return to the position where she was first seen, and this is the time which she takes to revolve round the earth. But as the sun has also been (apparently) advancing among the stars during this period, and the moon only shines by the sun's light, she has to move further to overtake him, and thus the period between one new moon and the next is slightly over 29 days; a lunar month is, however, reckoned as 28 days, and of these months there are thirteen in the year. The track of the moon among the stars, or her orbit, is an ellipse, which is inclined to the ecliptic at a small angle (about 5°), and cuts it at points called the moon's nodes. As the moon is an opaque globular body revolving round the earth, she is visible only by the reflected light of the sun, and in consequence appears to us to pass through a series of phases (Fig. 52). When her dark side is turned towards us she is invisible, but as she moves round her orbit her edge is illuminated by the setting sun and she appears to us in the western part of the sky as a crescent, the new moon, placed to the east of the sun, the horns of the crescent being turned away from the sun, *i. e.* pointing towards the east. On each successive night thereafter more and more of her surface is visible, and she

passes through the condition of half moon to that of full moon. After this period she begins to wane, passing through the condition of half moon to the gibbous or humpbacked stage, and then to the decrescent, where the horns are turned to the right, *i. e.* to the west. As she rises later and later every night throughout her phases, we find that while the new moon appears at sunset near the setting sun in the west,

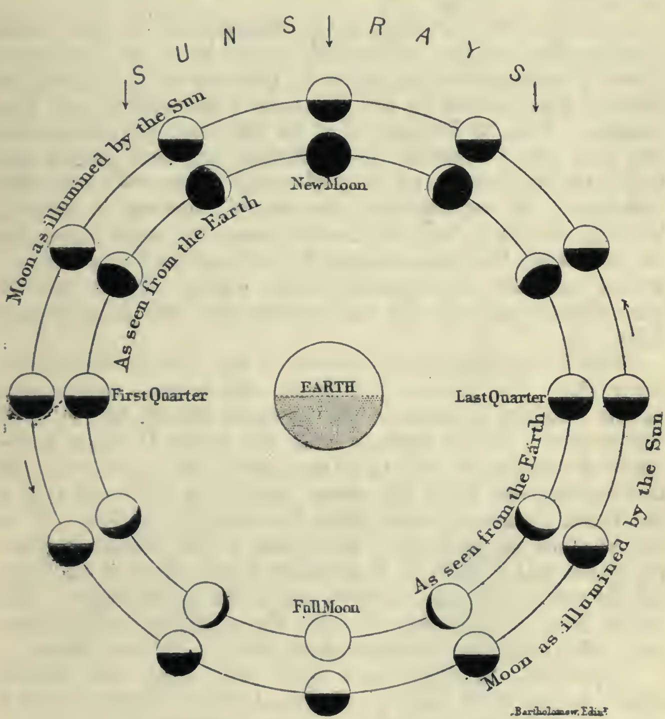

Fig. 52. The Phases of the Moon.

the decrescent is visible before the dawn, to the west of the rising sun, but in the eastern part of the sky. The stages when she appears to increase are called the waxing of the moon, those when she appears to decrease the waning of the moon. When she is either in conjunction as at new

moon, or in opposition as at full moon, she is said to be in quadrature, while at the half-moon stages she is said to be in syzygy.

At about the time of new moon, the unilluminated part of the moon's surface is sometimes faintly visible owing to light reflected from the earth's surface, and sent back again by the moon; this is described as the new moon in the arms of the old.

Although the average daily retardation in the rising, passing the meridian and setting of the moon is 51 minutes, there is considerable variation in the case of the rising and setting, this depending on the moon's declination and other causes. Thus it happens that in the northern hemisphere the full moon nearest the autumnal equinox shows very slight retardation in the time of rising for several successive evenings. In consequence, for several successive evenings the full or nearly full moon rises about the same time, that is, just about the time of sunset, forming the harvest moon, which appears unwontedly large owing to its position immediately opposite the equinoctial sun, and gives brilliant light.

Even a superficial examination of the moon's surface will show that it is always the same, the waxing and waning moons exhibiting parts of the features discernible in every full moon. This is because, like the earth, it has a movement of rotation as well as of revolution, but in this case the two movements have the same period, so that one side of the moon is never visible from the earth (Fig. 52). From the absence of refraction when the moon passes between the earth and a star, it is concluded that there is no atmosphere around it and therefore there can be no water. Life as we know it thus cannot exist there, for we cannot conceive of an organism independent alike of air and water.

Eclipses.—As the sun's light falls upon the various bodies in space, a shadow is formed behind them owing to the interception of the light, just as a terrestrial object upon which a strong light is thrown casts a shadow. If, therefore, the earth pass between the moon and the sun her shadow will fall upon the moon, producing the phenomenon known as an eclipse. Similarly, when the moon passes between the earth and sun her shadow will fall upon the earth; this similarly produces an eclipse. The one phenomenon is called a lunar and the other a solar eclipse.

A lunar eclipse can obviously only occur at the time of

full moon, when the moon is in opposition. Similarly, a solar eclipse can only occur when the moon is in conjunc-

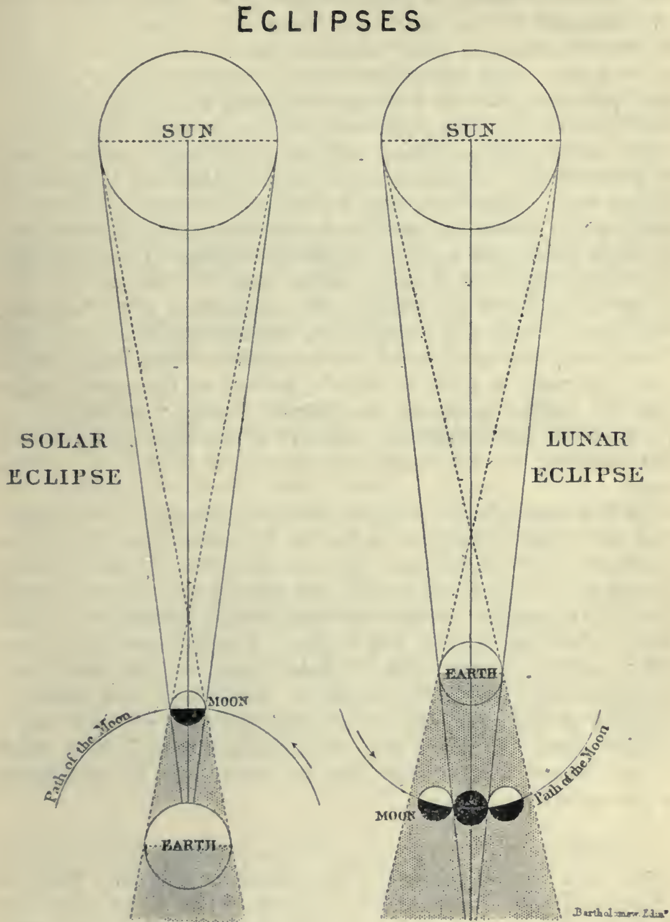

Fig. 53. The Causation of Eclipses.

tion, that is when it is new. At first sight it might be supposed that such eclipses should occur at every full and new moon. This would happen if the moon's orbit were in the plane of the ecliptic, but, as already seen, the orbit

is inclined at an angle of about 5° with this plane. Therefore an eclipse can only occur when the moon is at one of her nodes at the time when full or new moon occurs. As the motions of the moon are accurately known, the time of both lunar and solar eclipses can be foretold. It is a curious fact, and one which seems contrary to experience, that solar eclipses are far more frequent than lunar eclipses, for from two to five solar eclipses occur every year, while there is not even one lunar eclipse every year; nevertheless, in a given area far more eclipses of the moon are visible than of the sun. This anomaly is explained by the fact that at every place where the moon is above the horizon at the time of an eclipse, this eclipse is visible, whereas a solar eclipse is visible only over a very limited area.

In all eclipses we distinguish the central black shadow, the umbra, from the surrounding regions where a little light is received, this being called the penumbra. In a lunar eclipse the penumbra is scarcely visible, but when the moon passes into the umbra darkening is observed, which may be total or partial; the first condition occurs if at the time of opposition the satellite is on a node, the second if it is only near a node.

In the case of solar eclipses the penumbra is quite visible, and for persons within a radius of 200 miles the result is to produce a partial eclipse. On the other hand, for that part of the globe which lies within the umbra the eclipse is total, but the maximum area over which this occurs is a circle whose diameter is only 167 miles. We thus see the reason why, at any given spot, a total solar eclipse is a rare phenomenon, and why scientific expeditions are made to regions of the globe for the express purpose of observing a total eclipse. While a total lunar eclipse may last as much as two hours, a total solar one can never last for more than a few minutes.

Terrestrial Magnetism.—We may add to this chapter a short note on the subject of terrestrial magnetism, which is of great practical importance in view of the use of the compass by sailors as a means of finding the north. The earth behaves like a large magnet, as is easily seen by suspending a magnetic needle freely. If the needle is free to move in the horizontal plane only, one end of it points nearly to the north. The deviation from the exact north varies greatly in

different parts of the world, and is called the *declination*. Not only does it vary from place to place, it varies also in time, so that tables of magnetic variation require to be constantly published. The declination is described as east or west, according as the region to which the compass needle points is east or west of the geographical pole.

If the needle is suspended so that it is free to move in a vertical direction, it is found that it does not remain horizontal, but *dips* downwards at an angle which varies with the locality. This dip is called the *inclination* of the needle. At certain parts of the world there is no dip, and a line connecting all these places together is called the magnetic equator. It does not coincide with the geographical equator, but forms a sinuous curve not deviating greatly from it. At two places on the surface the dip is 90°, so that the needle points vertically downwards. These two places are called the magnetic poles, and are near, but not at the geographical poles.

In studying terrestrial magnetism still a third element has to be considered, this being the intensity of the magnetic force. This also varies, being least at the magnetic equator and greatest at the magnetic poles.

Isogonic lines are lines drawn through places having the same declination or variation, while *isoclinic* lines are those drawn through places having the same dip, and *isodynamic* those drawn through places where the magnetic force is of the same intensity. Maps showing such lines have to be redrawn frequently, for all three elements show secular variations, in addition to annual and diurnal ones. So far as at present known the subject of terrestrial magnetism is of no geographical importance, except in so far as the compass affords the geographer a means of finding his relative position.

CHAPTER XII

THE POSITION OF A POINT AND THE CHIEF MAP PROJECTIONS

Determination of Latitude and Longitude.—Position of a Heavenly Body.—Sea-level.—Great Circle Sailing.—Construction of Maps.—The Chief Projections and their Characters.—Scales of Maps.

DETERMINATION OF LATITUDE.—Now that we have considered the chief facts in connection with the shape and movements of the globe, we must discuss the problem of how the position of any point on the surface may be determined. In the case of a plane surface the position of a point is readily fixed by means of co-ordinates—that is, of two lines drawn at right angles to each other. Thus if a coin be lying on a rectangular table, its position is absolutely determined when we say that it is six inches from the side and three from the end.

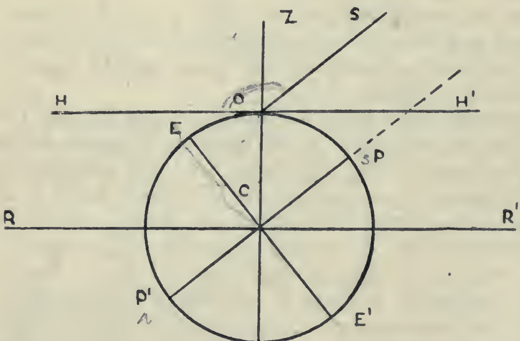

Fig. 54. The Sensible and the Rational Horizon. (For explanation see text.)

Now, we have already seen that we can draw on the surface of the globe a network of lines, made by parallels of latitude and meridians of longitude; these similarly enable us to find the position of a point on the surface of the sphere, so that the problem of the point resolves itself into the problem of how the latitude and longitude of a place may be found. Before, however, we can consider these two separate

problems, we must note the meaning of certain terms used in mathematical geography.

Let us take first the term *Horizon.* In Fig. 54 the circle represents a section of the globe, PP^1 being the plane of the poles, and EE^1 the plane of the equator. O is the position of an observer and Z is his zenith. To the observer the horizon is represented by a circle traced by the extremities of a circular plane passing through O and perpendicular to the line OZ; it is represented in the diagram by the line HH^1. This is the Visible or Sensible Horizon. But as the surface of the celestial sphere is infinitely distant, this plane would ultimately coincide with the plane represented by the line RR^1, which is drawn through the centre of the earth. This is the True or Rational Horizon. If S be a star, then its *Altitude* is measured by the angle made by a line drawn from the eye of the observer to it with the plane of the horizon, and in the diagram this altitude is expressed to the observer at O by the angle SOH^1. If the star is circumpolar, *i. e.* if for the observer it never sets, but appears to describe a circle round the pole, then it will appear to cross the meridian of the observer twice, the altitude necessarily differing in the two cases. The one crossing is called the upper culmination and the other the lower (see Fig. 55). As the star is describing a circle round the pole, the mean of the two

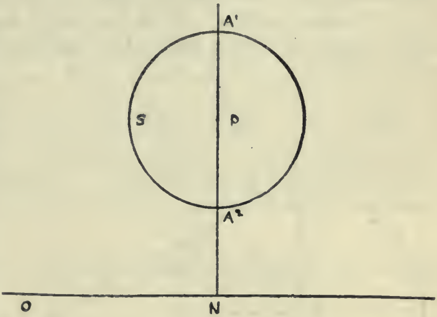

Fig. 55. Diagram to illustrate the apparent course of a circumpolar star.

P is the celestial pole, and S the star, which seems to travel round the pole in a circle, and never disappears below the horizon, which is indicated by the horizontal line. The meridian is indicated by the perpendicular, which cuts the horizon at the north point, marked N. An observer at any point on the horizon, *e. g.* at O, can take two altitude observations of the star, one when it crosses the meridian at A^1 and the other when it crosses it at A^2. The mean of the two observations will give the altitude of the pole, that is the latitude. A^1 is the upper culmination of the star, and A^2 the lower.

observations necessarily gives the position of the pole star, and this, as we shall see, is one method of finding the latitude.

To prove this we must first prove that the altitude of the pole at any place is the latitude of that place. Latitude is measured by the angular distance OCE (Fig. 54), where C is the centre of the earth. It could, of course, be equally measured by the distance OE, but the angular measurement is more convenient. As the equator is marked 0° and the whole circle includes 360°, the pole must obviously be 90°. Now in the figure it is clear that the angle OCE, *i.e.* the latitude of O, is equal to the angle R^1CP, or the distance of the pole above the horizon, because $PCO + R^1CP$ = a right angle, and PCO + OCE also equals a right angle. Therefore the problem of finding latitude is the problem of finding the altitude of the pole above the horizon. This may be done directly by means of the pole star, which is in the zenith at the North Pole. In this case the star lies along P^1P produced, and to see it the observer must look along the line OS, which is parallel to P^1P produced. The altitude of the pole star thus gives directly the altitude of the pole which, with a correction supplied by the nautical almanack, is the latitude required. The necessary observations here, as in the following case, are made with a sextant.

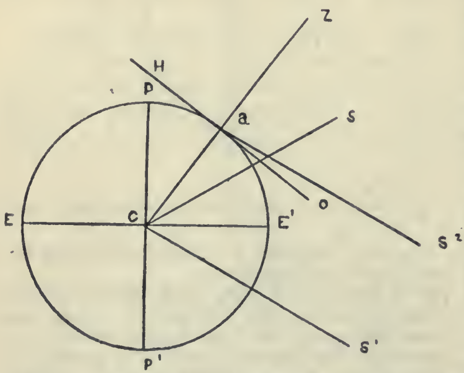

Fig. 56. Diagram to show how to find the latitude by means of the altitude of the sun. (See text.)

The line CS indicates the position of the sun on June 21, when the declination is 23½° N., and the line CS^1 its position on December 21, when the declination is 23½° S.; the difference in the polar distance in the two cases should be noted.

Where the pole star cannot be directly observed, the altitude of the pole may be obtained by the upper and

lower culmination of a star, as indicated above (see Fig. 55), but still another method often employed is by finding the meridian altitude of the sun. The diagram (Fig. 56) illustrates this method. As before, PP^1 is the axis of the poles, EE^1 represents the equator, C is the centre of the earth, and a is the position of an observer, and HO his horizon. Suppose the sun is in the position indicated by the line CS^1, which will happen on December 21, then to see the sun the observer must look along the line aS^2, and the altitude of the sun to the observer will be represented by the angle S^2aO. The distance of the sun from the zenith is represented by the angle ZaS^2, which equals the angle ZCS^1. Now, the angle E^1CS^1 is the sun's declination, the angle aCE^1 the latitude, and, further, the angle ZaO is a right angle, and = zenith distance + altitude. Thus we have altitude + zenith distance = 90°, and zenith distance = declination + latitude. That is:—

$l = 90 - (a + d)$ where l = latitude, a, altitude and d, declination.

Now we can find the altitude by observation, and the declination is given for every day in the year by a nautical almanack, and is known for the four dates—March 21, June 21, September 23, and December 21. Thus the altitude observation enables us to find the latitude.

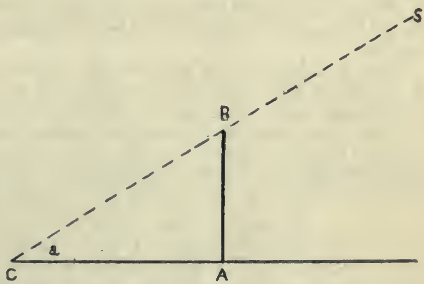

Fig. 57. Diagram to show how the altitude of the sun may be obtained roughly by means of a stick.

AB a stick, placed exactly vertical to the ground. CA the shortest, *i.e.* the noontide, shadow. CBS the direction of the sun's rays. AB and AC can be obtained by direct measurement, and by trigonometry (tan a = stick ÷ shadow), the angle a is readily obtained, or it can be obtained geometrically from a triangle drawn to scale, the angle being then measured by a protractor.

An actual problem may be worked as follows:—

(*a*) A certain fixed star was observed to cross the meridian at 5 p.m. on December 21, and again at 5 a.m. on the 22nd; its altitude at the first observation being 62° and at the second 38°.

(*b*) On the same date the sun was observed to reach its greatest altitude (16·5°) at 2 p.m. Greenwich time.

Explain how the latitude of the place may be determined from the observations under (*a*), and latitude and longitude from the observations under (*b*), and make the necessary calculations. (Oxford Sen. Local, 1911.)

(*a*) The two observations are obviously the upper and lower culminations of a star, so we need only add the two figures together and divide by 2 (see Fig. 55). Therefore lat. = 50° N. (*i. e.* $\frac{62° + 38°}{2}$).

(*b*) At the given date the sun's declination is 23½° S. Thus we have $x = 90° - (16·5° + 23\frac{1}{2}°)$ where x is the latitude required.

$\therefore x = 90° - 40°$, and $x = 50°$ N.

The sun reaches the meridian at 2 p.m. Greenwich time, therefore the local clocks are two hours behind those of Greenwich, and 15° of longitude go to one hour (see p. 153). Therefore the longitude is 30° W.

In point of fact the matter is much more complex than this would suggest, for a number of corrections have to be applied. It should be noticed also that the last method may be employed with a star instead of the sun if the declination of this star can be obtained from the nautical almanack.

The simplest general formula is to say that the complement of the declination is the polar distance, and if we add this polar distance to the observed altitude and deduct the sum from 180° we get the latitude. In the case of the sun due regard must, of course, be paid to the sign of the declination, *i. e.* whether the sun is north or south of the equator (see Fig. 56).

With this formula let us work the problem for the four dates, March 21, June 21, September 23 and December 21. The altitude of the sun at the point under discussion is on the different dates respectively 40°, 63½°, 40°, 16½°, and the declination is respectively 0°, 23½° S., 0°, 23½° N., making the complements, or polar distances, on the three occasions, 90°, 66½°, 90°, and 113½°. We thus have four equations:—

$$(1)\ 180° - (40° + 90°) = x, \therefore x = 50° \text{ N.}$$
$$(2)\ 180° - (63\tfrac{1}{2}° + 66\tfrac{1}{2}°) = x, \therefore x = 50° \text{ N.}$$
$$(3)\ 180° - (40° + 90°) = x, \therefore x = 50° \text{ N.}$$
$$(4)\ 180° - (16\tfrac{1}{2}° + 113\tfrac{1}{2}°) = x, \therefore x = 50° \text{ N.}$$

We may add one other problem for the southern hemisphere. At a place south of the equator the altitude of the sun at noon on June 21 is 64°. What is the latitude?

Polar distance (measured from S. Pole) = 113½ (*i. e.* 90 + 23½). Altitude 64°.

$\therefore 113\frac{1}{2} + 64 = 180 - l.$

$l. = 180 - 177\frac{1}{2} = 2\frac{1}{2}°$ S.

Determination of Longitude.—The determination of longitude is more difficult. The simplest method, and the one now almost exclusively used at sea, is to find the apparent noon by the sun's meridian passage, and then compare this local time with Greenwich time as shown by a chronometer. The very simple principle involved is indi-

cated in the example worked above. On land, however, it is difficult to carry a chronometer about, and in civilised regions Greenwich time is often obtained by means of the electric telegraph. Where this is not available the moon is employed in obtaining longitude by a method known as lunar distances, but this is relatively inaccurate at best, and is too complicated to be considered here.

Position of a Heavenly Body.—In the preceding discussion we have considered the methods of finding the position of a point on the surface of the sphere. Let us note for a moment the other problem—that of determining the position of a heavenly body. There are various methods of doing this; we shall consider only one, which determines the position at a given place and at a given time, for, owing to the movements of the earth, the heavenly bodies constantly change in position. The diagram (Fig. 58) illustrates the method employed in doing this. O is the observer, the horizon being indicated by an ellipse; the cardinal points are shown by the letters S, E, N, W. Z is the zenith, P the celestial pole, or point where the axis of the earth's rotation, prolonged indefinitely, meets the celestial sphere. The line NZS is the celestial meridian, which passes through the zenith and the poles of the celestial sphere, while EZW is the prime vertical, the vertical circle passing through the east and west points of the horizon. ZM is another vertical circle, R marking the position of a heavenly body at a given period of time. To fix the position of this body two coordinates are required. The one is given by the altitude, and this we have already considered. The other is given by the *azimuth*, which is measured by the arc SM, if the

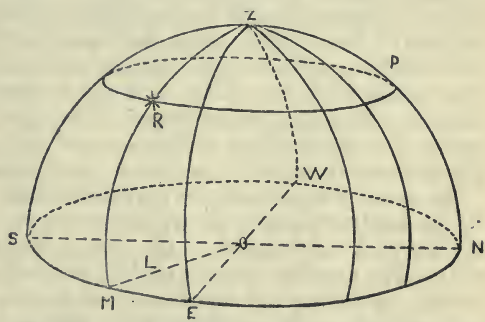

Fig. 58. A diagram to illustrate a method of finding the position of a heavenly body. (For explanation see text.)

South Pole be taken as the starting-point, and equally, if this condition is satisfied, by the angle SZM, which subtends this arc. In other words, the azimuth of a body is the arc of the horizon intercepted between the south (or north) point of the horizon and the foot of the vertical circle passing through the body, or, equally, it is the angle at the zenith between the celestial meridian and the vertical circle passing through the body. To the observer at O the azimuth is the bearing of the body R in relation to the meridian. We can equally speak of the azimuth of a point on the surface of the earth. Thus the azimuth or bearing of the point L is the point of intersection of the vertical circle passing through it with the horizon, measured from the south (or north) point, and is expressed by the angle SOM. It thus gives the exact bearing of the point L from the observer O, measured from the meridian. This is a point of considerable importance in connection with surveying, and the azimuth may be either taken by a direct measurement from the meridian, or by taking first the bearing of the sun and adding or subtracting the horizontal angle, according to circumstances.

To make this clearer we may note that, measuring from S, the southern point, in an eastern direction, we find that a point at S has azimuth $= 0°$, one at E has azimuth $= 90°$, one at N, azimuth $= 180°$, at W, azimuth $= 270°$; at intermediate positions the values are, of course, intermediate.

Sea-level.—The cartographer, before he can construct maps, must not only be able to determine the latitude and longitude of the points with which he has to deal, he must also have a base-level. This base-level is taken as sea-level, but this is not, as might be supposed, a perfectly fixed datum. On the British Ordnance Survey maps the datum (p. 32) is the "assumed mean level of the sea at Liverpool," which is probably more than half-a-foot below the general mean level of the sea. By mean level here is meant mean tide-level. Over the surface of the ocean generally there is undoubted variation in the level of the sea, a variation which is partly due to temporary causes, such as the winds; to atmospheric pressure, which causes the level to sink over regions where the barometer is high, and to rise over regions where it is low; to differences in salinity, and so forth. In addition to these variable causes, there are other permanent inequalities due to the attraction exercised by the land, and to the varying forms of shores. The land attracts the water

towards it, and the higher the land which fringes the coast the greater the attraction and the higher the level of the sea. The net result is that we must regard the sea-level from which the cartographer's calculations are made as a pure convention, for the actual level of the sea varies greatly. Many figures have been given as to the maximum possible variation, but according to Penck the maximum possible elevation or depression must be less than 770 feet.

Great Circle Sailing.—The shortest line between any two places on the surface of the globe is along an arc of a Great Circle. This may be realised by reflecting that the shortest distance between any two points is a straight line, and obviously the greater the circle the less the curvature, and the smaller the circle the greater the curvature. To put the matter in another way, a straight line is part of a circle whose centre is infinitely distant, and therefore the shorter the radius of a circle the greater the deviation of its circumference from a straight line. The fact can, however, be best appreciated by actual measurement on the globe. If we have two ports of which one lies SW of the other, two courses are possible to a ship travelling from one port to the other. The one consists in setting the ship's head for the direction SW and travelling steadily along this line till the port is reached; this is called rhumb-line sailing. The other consists in finding the arc of the Great Circle which connects the two places and sailing along it, a course which may involve several changes of direction. Now, as all the meridians are Great Circles but of the parallels only the equator, there are certain cases where the rhumb-line and the Great Circle coincide. Thus a ship at a port on the equator is following a Great Circle if she moves north, south, east or west. Again, if the two ports lie in low latitudes, one on each side of the equator, or if in any latitude they lie nearly on the same meridian, the difference between the two courses is small. On the other hand, in high latitudes where the two places lie nearly on the same parallel, the difference between the two courses is considerable, and Great Circle sailing therfore enables ships crossing the North Atlantic from or to North-western Europe to save much time. Similarly in the Southern Atlantic the Great Circle route between the Cape of Good Hope and Cape Horn effects a great saving; in this case as much as 200 miles. The student should calculate the difference

between the two courses for a number of routes, remembering that a degree of latitude contains about 60 geographical miles, or 69 statute miles, while the length of a degree of longitude varies from 69 miles at the equator to 0 at the poles. Exact figures are given in books of reference, or may be obtained by the rule that in latitude a the length of a degree $= 69 \times \cos a$. It is well to remember that in latitude 51° (approximately the latitude of London) the length of a degree of longitude is 43·4 statute miles ($69 \times \cos 51° = \cdot 69 \times 69 = 43 \cdot 4$). A book of mathematical tables gives the natural cosines for all angles.

Construction of Maps.—We have seen from what has just been said that we can draw meridians of longitude and parallels of latitude over the surface of the globe, and thus form a network by means of which the position of a point may be determined. We have seen, further, that it is comparatively an easy matter to fix the latitude of any point, *i. e.* the particular parallel upon which the point should be placed on the globe, while it is a much more delicate matter to obtain its longitude. This, however, can be done, and the result is that we can readily represent the globe upon a small sphere, the position of every point being fixed by previous determination of its latitude and longitude. But globes when large are excessively cumbersome, and when small they give no details in regard to the lands. The representation of the surface, or of parts of it, upon a flat surface or map, therefore, at once presents itself as desirable. Here, however, we are at once faced with a difficulty, which is readily realised if a large ball is taken. If from this ball we cut out a very small fraction of the area, it is possible to spread out this piece on a flat surface, such as a table, without great difficulty. If, on the other hand, we cut out a section of considerable size, relatively to the whole, it is not possible to flatten it out upon the table; it continues to show an obstinate curl, despite all our efforts. If the ball is of indiarubber, we may tack one edge of the section firmly to the table, and then by pulling obtain an approximately plane surface, without obvious wrinkles, but the larger the piece the more difficult this is, and the more distortion results. Thus no map of a considerable part of the globe can be an accurate representation of it, and the greater the area represented, the greater the distortion.

Projections.—As no part of the spherical surface of the

globe can be transferred to a flat surface without undergoing modification, it is obvious that the parallels and meridians must also be modified—they can only be *represented* on a map, not *transferred* directly to it. In cartography the name projection is applied in a wide sense to the network of lines on the map which represent the spherical co-ordinates of the globe, but we should note that strictly it has a more limited signification. In a mathematical sense it signifies much the same as shadow, or, more precisely, if through every point of a curved surface we draw straight lines to meet a plane surface, and connect the marked points on the plane by a line, then this line is the *projection* of the curve. To realise the meaning of this take half an orange skin, and lay it on a piece of paper with the convex side downward. Mark with a pencil a curve on the inner side of the orange skin, and then take a long pin and prick through along this line, so that the point of the pin reaches the paper below. Then connect the pin-pricks on the paper by a line, and you have the projection on the paper of the curve on the orange skin. The so-called true projections of the cartographer are obtained roughly in this fashion, though, as we shall see, in place of a flat piece of paper he is often constrained to take a cone or cylinder of paper in order to obtain his projection. But, in addition to these true projections, the cartographer employs also a number of purely conventional nets, which he adopts in order to obtain a special end. It is convenient to extend the word projection to cover these also.

The next point to notice is that no projection can be perfect. In representing the feature of the globe upon a plane surface, three types of error can be recognised: (1) the angles may be altered; (2) the distances on the map may not accurately represent the distances on the globe; (3) a given area on the map may not accurately represent the same area on the globe. Now, speaking broadly, if the cartographer sets himself to exclude one of these errors, his map necessarily shows the other two to a greater or less extent. Further, in all projections the errors present increase in travelling from the centre of the map. The net result is that the larger the area to be represented the more difficult it is to find a suitable projection, and the particular projection chosen should be considered in relation to the position in latitude and longitude, and the extent of the area to be

represented, and the object for which the map is intended. For general purposes it is desirable that all three errors should be as small as possible, but in certain special cases it may be desirable that attention should be given to the reduction to a minimum of one type of error, even though the others become very large. From this point of view we can distinguish three types of projections—

(1) *Equiangular.*—Here the angles on the map are equal, or nearly equal, to those on the sphere. Thus, meridians and parallels cross one another at right angles, and objects have the same bearing to one another as on the globe. Examples are the Stereographic projection, (Fig. 59), and also the familiar Mercator's projection (Fig. 62). The latter has, further, the great advantage that a mariner may lay down his course on it as a straight line, by merely noting the bearing of the port at which he wishes to arrive from the port of departure. The course thus laid down is, however, a rhumb-line course (*cf.* p. 175).

Fig. 59. The Stereographic Projection.

(2) *Equal-area or Equivalent.*—Here if a small area of the map be taken, *i. e.* the area enclosed between two consecutive meridians and two consecutive parallels, we find that this area has always the same relation to the similar area on a globe. Such a map is therefore very suitable for measuring areas, and for plotting distributions. Mollweide's projection (Fig. 63) is a good example.

(3) *Equidistant.*—Here distances measured from the centre of the map are proportional to those measured on the globe, so that, for the centre of the map, distances are correctly indicated. The Globular projection (Fig. 61) is an example.

Though there are a very large number of map projections, these may be reduced to relatively few types. Thus, if we project the points of the globe on a plane surface, we get the Horizontal projections, of which the Orthographic and Stereographic are examples. If we roll a cylinder round the globe, project the points on its surface, and then unroll it, we have the Cylindrical projections, of which Mercator's is an example, and Mollweide's merely a modification. Again, if we place a cone over the globe, and project the points on the inner side, then spread out the cone, we have the various forms of Conical projections, largely used in atlases for representing continents and countries. We shall examine a few of these in a little more detail.

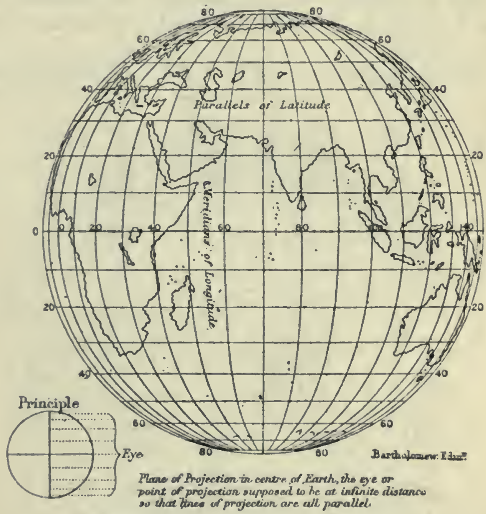

Fig. 60. The Orthographic Projection.

Orthographic (Fig. 60).—The principle involved here is relatively simple. Suppose we look at the sphere from an infinite distance, so that the rays of light become parallel, and suppose it to be transparent, so that the rays of light would pass through it to a plane surface placed on or within the sphere. The parallels of latitude of the globe would then be projected on the plane as parallel lines, but, owing

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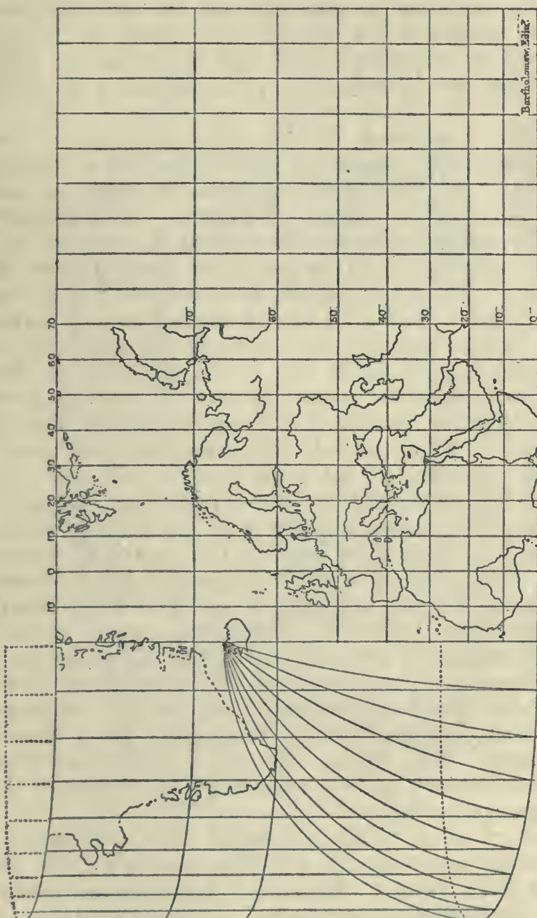
to the effect of perspective, their distances apart are unequal, diminishing rapidly towards the limits of the projection; the meridians are generally ellipses, and the distances between them also diminish towards the margin of the map. Thus, while the central region of the map is tolerably accurate, there is very great compression at the margins. This projection is not suitable for maps of the globe, but is employed for astronomical purposes, *e. g.* for maps of the moon.

Stereographic (Fig. 59).—Suppose, next, that the observer, instead of being infinitely distant, is placed on the sphere itself, and a plane be drawn through the centre of the globe. Then if lines be drawn from points on the other surface of the globe to the observer, we shall have a projection on the central plane. In this case the great circles passing through the centre of the projection are straight lines, and all the others are shown by circles or sections of circles. In this case there is compression towards the centre of the map instead of towards the outer circumference. As already seen, this is an equiangular projection. Three types of this projection are recognised, according as the observer is supposed to be placed at the equator, at the pole, or at some other point. This projection is useful when large areas have to be represented, and is often used for the hemispheres; in this case it is noticeable that there is considerable

Fig. 61. The Globular Projection.

exaggeration of areas at the margin of the map. This exaggeration can be avoided by placing the observer outside



The Plane of Projection is the surface of an imaginary cylinder surrounding the globe and touching its surface at the equator. At the equator its scale agrees with the globe but as each parallel of latitude becomes a great circle equal to the equator the scale increases as we go north and south. The latitude is however increased in same proportion as the longitude. Mercators projection is the only one which gives the true direction of one point in relation to another and is therefore most used for the purposes of Navigation.

Fig. 62. Mercator's Projection. Note the enormous exaggeration of Greenland as shown to the left.

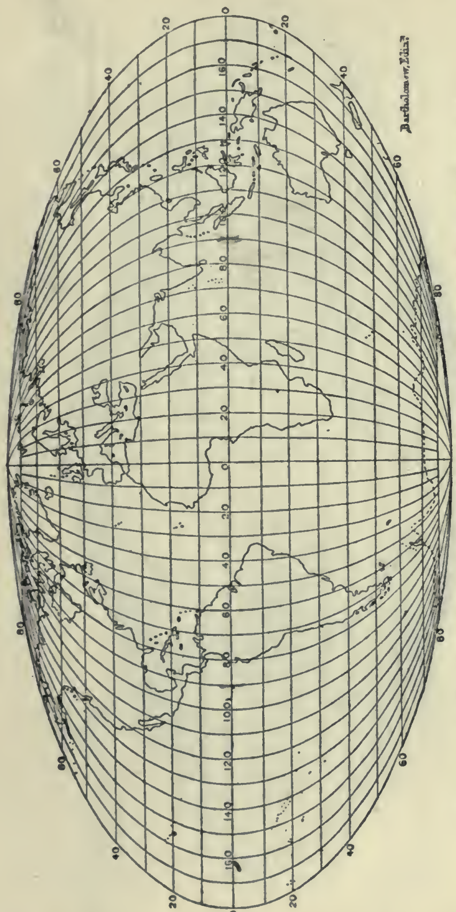
the sphere, as in the projection called Globular (Fig. 61), or equidistant. The distance of the observer from the sphere can be so arranged that the distances between the

parallels and meridians throughout is nearly equal, and they are drawn equal, so that this is an equidistant projection. In this case there is still considerable difference in the scale at the middle and edge of the map, but between the same parallels the meshes of the net are more nearly equal than in the preceding projections, and this is, therefore, often preferred to the stereographic for the hemispheres in school atlases.

Let us take next some of the more important of the cylindrical projections, beginning with MERCATOR'S PROJECTION (Fig. 62). In cylindrical projections we suppose that a roll of paper is placed round the globe. In Mercator's projection the cylinder touches the globe at the equator, and parallels and meridians are projected as straight lines on the cylinder. But in the globe the meridians converge towards the poles, and cannot be represented on a cylinder. The way in which Mercator got over this difficulty may be represented by cutting gores out of the cylinder, so that these fit closely over the globe. If now we lay our gores out on the table, we find that our map shows big gaps at top and bottom. If we fit into the gaps the pieces which were left of the cylinder, we shall greatly exaggerate the width of the degrees of latitude, the exaggeration increasing as we approach the poles, and throwing out completely the proportion which should exist between the lengths of degrees of latitude and longitude in the high latitudes. If we remedy this by exaggerating the longitude as much as the latitude, we have Mercator's projection. Some of its merits we have already indicated, but it should be noted that it has the great demerit of enormously exaggerating the areas of the lands in high latitudes, which for geography are the least important because the least developed parts of the globe. Thus, Greenland looks larger than Africa, and Alaska nearly as large as the United States. At the same time, the forms of the continents are well preserved.

Two types of maps which are based upon a cylindrical projection, with modifications, are MOLLWEIDE'S (Fig. 63) and SANSON-FLAMSTEED'S (Fig. 64). Both are equal-area projections. Mollweide's, also called the Homalographic, is constructed by drawing a circle equal in area to one hemisphere; the whole globe, if represented, taking the form of an ellipse. The equator and central meridian are straight lines intersecting at right angles, and the parallels are all

straight lines, while the other meridians are elliptical arcs. There is here angular deformation towards the periphery of



This is an equal-area projection. The complete circle on the map is made to equal the world hemisphere. Parallels are so drawn that the zone enclosed by them bears the same relation to the area of the circle as the similar zone on the earth bears to the hemisphere. The meridians are ellipses cutting the parallels at equal distances.

Fig. 63. Mollweide's Projection.

the map, but this is less marked than in Sanson-Flamsteed's projection. In it the central meridian and equator are again straight lines at right angles, and the parallels are straight lines, but the other meridians are curves of varying form,

constructed by marking off on each parallel lengths equal to a degree of longitude at the latitude of the parallel, and

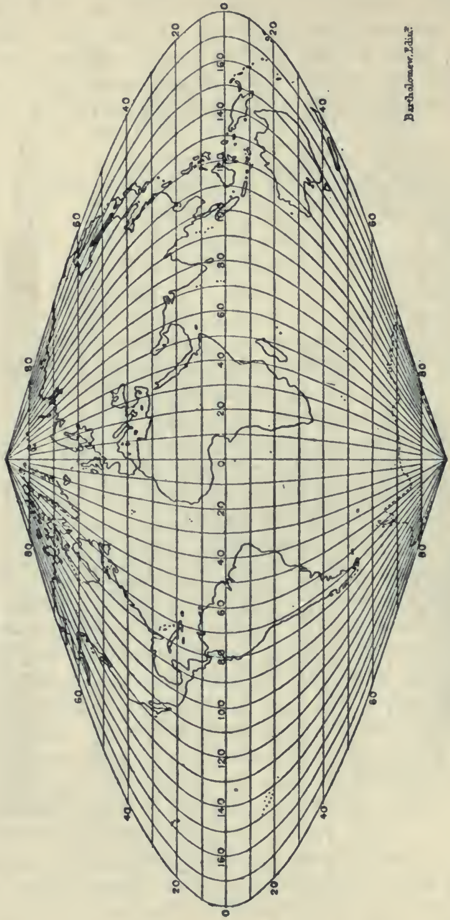
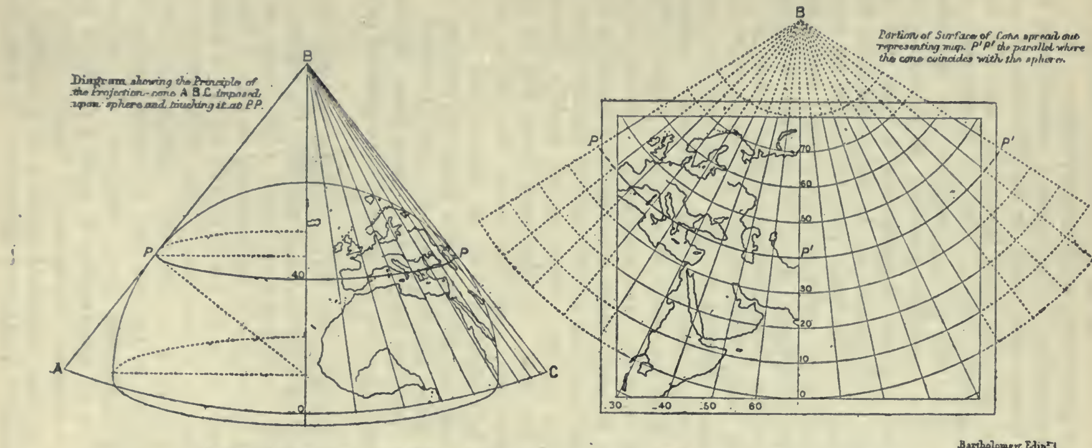


Fig. 64. Sanson-Flamsteed's Projection.

drawing lines through these points. Towards the margin of the map the angles between parallels and meridians are greatly diminished, so that much distortion is caused. Therefore the projection is only used for continents, not hemi-



The Plane of the Projection is the surface of an imaginary Cone imposed on the Sphere and touching its surfaces along the parallel of 40°–P P. Distances measured along that parallel on the map are absolutely correct as they exactly coincide with the globe. But the scale is distorted to the north and south of tangential parallel according to distance away from it.

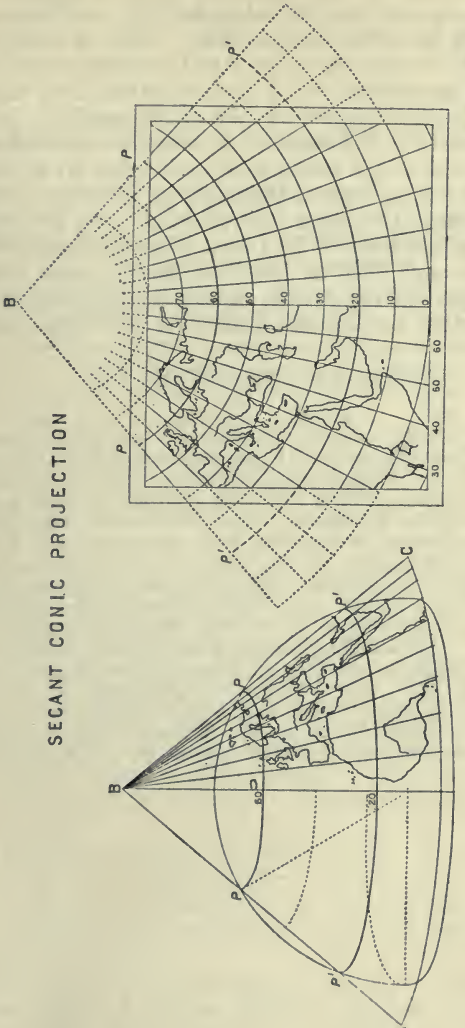
Fig. 65. The Simple Conic Projection.

spheres, and is most suitable for countries near the equator. Africa is sometimes drawn on this projection.

Conical Projections.—There are a considerable number of variants of these, some form or modification of a conical projection being the one most frequently used for maps of countries and smaller areas. Conical projections can be constructed which will be equiangular, or equivalent, or equidistant. The principle involved is relatively simple. Suppose we roll a piece of paper into a cone and place it on the globe so that the axis of the cone coincides with the axis of the poles. The cone will be found to touch the globe in a certain area, and a belt above and below this area will lie close to the globe. The cone should be so arranged that the area where it touches the globe is made the central parallel of the map, when it will be found that if points of the globe are projected on the cone, then the resultant map will be correct for the central region, distortion increasing with distance from this central region (Fig. 65). In order to increase the area over which the map is correct, a modification is used which consists in supposing the cone to touch the sphere, not at the central parallel, but in two parallels, placed half-way between the middle and extreme parallels (see Fig. 66). In this case there will be no error at the two parallels, and the errors elsewhere will to a great extent balance. It will be noted that on conical projections meridians are straight lines converging towards the top of the map, and parallels are arcs of circles.

A number of other projections have been devised, but those described may serve to illustrate the general principles involved.

Scales of Maps.—We have already (p. 26) discussed briefly methods of representing altitude on maps, but we may add to this account of projections a brief note on scales. The scale of a map may be represented in one of two ways, either by a fraction, *e. g.* 1/1,000,000, or by a linear scale showing miles or kilometres. The disadvantage of the linear scale is that it is naturally expressed in the linear measure employed in the country of origin, which may be only partially intelligible to a foreigner; the advantage is that with a pair of compasses, or even a piece of paper, it is possible to measure distances at once. The universal intelligibility of the fractional method is discounted by the need for calculation in finding distances. It does, however,



Bartholomew, Edin.

The Cone is in this case supposed to be sunk into the Sphere so that it cuts its surface along two parallels P P and P' P' and the map has therefore the advantage of coinciding with the globe along two parallels instead of one as in the simple conic.

Fig. 66. Modified or Secant Conic Projection.

permit maps to be very readily compared together, and the linear distances can be calculated by recollecting that 63,360 inches go to the statute mile. Now; if a map is on the 1:1,000,000 scale, we know that 1,000,000 inches on the surface are represented by 1 inch on the map, therefore 1 inch on the map represents 15·8 miles nearly. To some extent the fraction 1:1,000,000 is taken as a standard for large-scale maps, other scales being multiples, so as to allow for the ready comparison of the maps of different countries; *e. g.* the German Ordnance Survey Map is on the scale of 1:100,000, the French War Office map on the 1:200,000 scale, and so on. This is, however, not the case with our own Ordnance Survey maps, which are on the scale of 1 inch to a mile, that is, the fraction is 1:63,360.

REFERENCES TO SECTION IV.

The general books on Physical Geography already named devote more or less space to the subject of this section, especially de Martonne's book. Greater detail can be found in an astronomy book, *e. g.* Herschel's *Astronomy*, or Lockyer's *Elementary Astronomy*. A nautical almanack is essential for working problems; Brown's *Nautical Almanack*, published at Glasgow, may be mentioned. *Hints to Travellers*, published by the Royal Geographical Society (two vols., many editions), is full of interesting information on points connected with surveying, the finding of position and so forth. Elderton's *Maps and Map Drawing* (London, 1906) is a small book, which will be found useful, and Simmons and Richardson's *Introduction to Practical Geography* contains many useful problems. Geometrical solutions of many points connected with mathematical geography are given in Hughes' *Practical Geography for Schools* (Oxford, 1887). For details as to map-making and surveying reference should be made to Close, *Text-book of Topographical and Geographical Surveying*, published by the Stationery Office (1905), and Reeves' *Maps and Map-making*, published by the Royal Geographical Society (1910).

SECTION V—THE ATMOSPHERE

CHAPTER XIII

GENERAL CHARACTERS OF THE ATMOSPHERE, AND ITS TEMPERATURE VARIATIONS

Composition of the Atmosphere.—Its Height.—Physical Properties of Air.—Measurement of Temperature.—Sources of Heat.—Temperature Conditions over Land and Sea.—Solar and Physical Climate.—Diurnal Variation of Temperature.—Mean Annual Temperatures and Isothermal Maps.—Range of Temperature.—Distribution of Temperature over Surface.

Composition of the Atmosphere.—We saw in the Introduction that physical geography concerns itself with the interaction of lithosphere, atmosphere and hydrosphere. Now that we have considered the general characters of the land and the forces which play upon it, and the relations of the earth as a planet, we must turn to the discussion of the atmosphere and the hydrosphere. Of the two the atmosphere is obviously more important, for its influence is felt everywhere, while that of the sea is more limited.

The atmosphere consists of a mixture of gases; there being in dry air 78 per cent. of nitrogen, an inert gas, about 21 per cent. of oxygen, 0·94 per cent. of argon, a gas which has only recently been separated from nitrogen, and some other gases in very small amounts. Carbonic acid gas is present in small but nearly constant amounts, averaging 0·03 per cent.

Air always contains a greater or less amount of water vapour, and it is always more or less impure, having fine particles of dust suspended in it. These particles are of great importance in connection with the precipitation of moisture (*cf.* p. 224).

Height of the Atmosphere.—The atmosphere forms an envelope which the globe carries with it in its movements in space, and its thickness is a question of considerable theoretical importance. The densest layer, which is also

the most impure and the most heavily loaded with water vapour, is that which lies nearest the earth. Here it is that the great variations in temperature and pressure occur, and here takes place that circulation of water which is of so much importance to man. This layer is not more than 10,000–13,000 feet thick. Above 13,000 feet the amount of water vapour is only a quarter of that at the surface of the earth. The atmosphere, of course, extends upwards to far beyond this point, but its density has greatly diminished. It is calculated that half the total weight lies below a plane lying 19,000 feet above sea-level, three-quarters below a plane 36,000 feet up, and seven-eighths below one lying at 54,000 feet, or rather more than ten miles. Various cosmic phenomena, however, lead to the conclusion that up to 100 miles, or even more, a rarefied atmosphere is still present. The composition of the upper air, however, is very different from that of the atmosphere as we know it; indeed, it is believed to consist largely of the gas hydrogen. Further, temperature conditions in the upper layers are very different from those in the lower layers of the atmosphere. Thus at levels above about 7–9 miles the temperature seems to be constant and to average about $-70°$ F. ($-58°$ C.), forming the so-called isothermal or advective layer.

Physical Properties of Air.—As air is simply a mixture of gases it behaves like any other gas, being subject to the same laws as they. From the human point of view the most interesting points in regard to it are the variations in temperature, pressure, and the amount of water vapour. Like all gases, air expands when heated, and as it thus becomes lighter it tends to rise. This is well illustrated in a heated room, where it will be found that the air near the ceiling is hotter than that near the floor. In this case the upper layers of air are confined by the ceiling, but in the open they would rise, and thus diminish the pressure below. In consequence there would tend to be an indraft of air from adjacent regions, and we thus reach the conception of wind, or air in movement, which is closely associated with pressure. Again, if air be cooled it becomes denser, and, further, it is incapable of carrying as much water vapour as before. If it were near saturation-point before cooling, the water vapour will be condensed with the cooling, and will appear as mist, rain or snow, according to circumstances. We thus realise that meteorologist and climato-

logist alike are concerned with three separate problems in connection with air: (1) its variations in temperature; (2) the variations in pressure, with which is associated the amount and direction of the wind, both phenomena determined by the distribution of pressure in the atmosphere; (3) the amount of water vapour and the resultant precipitation, and, as clouds tend to hide the sun, with this subject the amount of sunshine is related. All these three elements are capable of instrumental measurement, and as our senses only give us very vague perceptions (*e. g.* as regards temperature variations), or none at all, except when the variation is very great (*e. g.* as regards pressure variations), of the extent to which change is occurring or has occurred, all scientific study of meteorology must be based upon instrumental observations, and thus involves dealing with masses of figures. Thus, in discussing the subject it is necessary to avail ourselves of graphs and the other means by which mathematicians represent to the eye the results obtained by the treatment of many separate observations. Before studying, therefore, either that average succession of weather conditions which we call climate, or the subject of weather, which is the sum total of the meteorological conditions at a given time and place, we must first discuss some points in connection both with the observation of variations in temperature, pressure and precipitation, and with the various methods of representing the results obtained.

Measurement of Temperature.—Taking the climatic factors in the order already given, we may begin with a discussion of temperature. Our senses, as already suggested, give us only very unreliable indications of temperature variations. Thus in our ordinary use of the words *cold* and *warm* as applied to weather, expectation plays a large part. We call a temperature of 50° F. warm in winter but cold in summer. Further, frosty days with little wind are felt and described by many as warmer than days when the temperature is above freezing, but the air is damp and the wind strong. Obviously, therefore, an instrument is necessary to check our sensations. At all usual temperatures a mercury thermometer is used for this purpose. In making a mercury thermometer a uniform glass tube is selected, with a bulb at one end. The bulb is filled with mercury, and this mercury is then raised to boiling-point. The amount of mercury necessary to fill the tube to over-

flowing at boiling-point has been previously ascertained by trial, and when the whole tube is so filled, and all air has been thus driven out, the tube is sealed, and the mercury allowed to cool. As it cools it contracts, leaving a vacuum above. The tube has a very narrow bore, and with any rise in temperature a thin thread of mercury appears in it, the height of the column being directly proportional to the amount of heat applied.

The next point is to construct a scale. Two heat phenomena, occurring at widely different temperatures, are of such enormous importance in human life that they are taken as fixed points in the formation of any scale. These are the freezing-point of water and its boiling-point. In the Centigrade, the simplest and most satisfactory scale, the one of these is numbered 0 and the other 100, and the scale is divided into 100 equal parts, or degrees, between these two fixed points. In the Fahrenheit scale, still commonly used in English-speaking countries, the freezing-point is called 32, and 0 is the point which Fahrenheit believed (quite erroneously, of course) to be the lowest temperature obtainable. He further called boiling-point 212, so that there are 180 degrees between freezing-point and boiling-point, as compared with 100 in the Centigrade thermometer. Still another scale is that of Réaumur, where freezing-point is 0, but boiling-point is 80 instead of 100. Students should practise the conversion of one scale into another, especially that of Fahrenheit into Centigrade, and vice versa. The method of conversion is conveniently summed up as follows—

$$\text{F.} = \tfrac{9}{5}\text{C.} + 32 = \text{R.} + 32.$$
$$\text{C.} = \tfrac{5}{4}\text{R.} = \tfrac{5}{9}(\text{F.} - 32).$$
$$\text{R.} = \tfrac{4}{5}\text{C.} = \tfrac{4}{9}(\text{F.} - 32).$$

Unfortunately, however, the constant use of Fahrenheit temperatures in daily life gives this scale a significance which the others do not possess for most people. It is well, therefore, to make an effort to learn the Centigrade equivalents for a few often-used temperatures, so that their significance can be perceived immediately, and without the need for calculation. Thus, 10° C. is the equivalent of 50° F., a common air temperature in this country, and the normal blood temperature, 98·4° F., is expressed on the Centigrade scale as 36·9° C. This is a good hot-bath temperature, and

is an excessively hot shade temperature for air. In the following chapters both scales are used.

In order to affix a scale to a thermometer it is usually stated that the instrument is inserted in melting ice to give freezing temperature, then exposed to steam from boiling water to fix the boiling-point, the graduations being inserted between these two fixed points. In point of fact, it is rare to find a thermometer which shows both these points, for this would mean either a tube of excessive length, or a very coarse graduation. A thermometer to be used to measure shade temperatures is rarely graduated much above 90° F. or 32° C. On the other hand, the grading goes considerably below 0° C., the figures below that point being marked with a negative sign, and the instrument similarly registers considerably below 32° F.

Sources of Heat.—Having now described the instrument with which temperature observations can be made, the next point is to settle the kind of observations which it is desirable to make, and this cannot be determined without some knowledge of the causes of the chief variations.

For practical purposes it may be said that the atmosphere receives all its heat from the sun, for the amounts received in other ways, *i. e.* from volcanoes, hot springs, and so forth, are too local and insignificant to affect the general problem. Now, as we have already seen that the earth is continually altering its position in relation to the sun, we have here an obvious cause of temperature variations. As a result of the rotation of the earth upon its axis all parts of the surface have an alternating day and night. During the day each part of the surface, therefore, receives the heat of the sun, while during the night it is deprived of it. Further, as we have seen, while day and night are permanently about twelve hours long at the equator, at the poles we have a six months' night and a six months' day; the intervening latitudes showing intermediate conditions. It is obvious, therefore, that, other things being equal, the area with the longer day receives more heat than the area with the shorter day. Here, however, another factor intervenes. In the first place, owing to the rotundity of the earth the amount of heat received per unit area is not the same at all latitudes. This is shown by Fig. 67. If (1), (2) and (3) represent bundles of solar rays falling upon the surface, then it is obvious that B, the area over which the rays

in (2) extend, is smaller than A or C, and therefore the amount of heat received per unit area will be greater at B than at A or C, and greater at C, which is nearer the equator, than at A, which is further from it. Further, as a considerable amount of heat is absorbed by the atmosphere, shown by the outer ring in the diagram, and the more obliquely the rays strike the surface the greater the depth of atmosphere they have to pass through, the total amount of heat which falls upon A must be less than that which falls on B, and this still further diminishes the amount received per unit area.

The diagram represents the condition at the equinox, but the effect of the tilt of the earth's axis, combined with its movement of revolution, causes, as we have seen, the phenomenon of the seasons, and produces a seasonal variation in the amount of heat received.

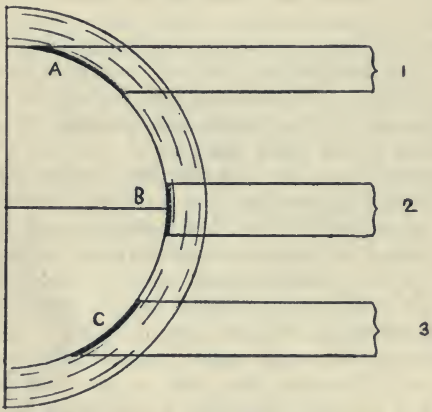


Fig. 67. Diagram to show differences in the amount of solar energy received per unit area in different latitudes. (For explanation see text.)

We thus reach two conclusions in regard to the amount of heat received at the surface. (1) Everywhere there will be a difference between the amount received by night and by day, causing a diurnal variation in temperature. (2) Everywhere there will be a seasonal difference in the amount of heat received, which will be least at the equator, and greatest at the poles, where the two seasons coincide with the prolonged night and day, so that the seasonal variations coincide with the diurnal.

From (2) it might be supposed that latitude would be the determining factor as regards temperature, and we have thus the old and simple division of the surface into tropical,

temperate and arctic zones, according to the amount of heat received. But the intervention of a number of secondary factors introduces modifications which reduce from the human standpoint the importance of this simple division. One of these secondary factors is the fact that the amount of heat received is only one of the elements of climate, rainfall being at least equally important, so that a rational division of the globe into climatic zones must take this into account. Leaving this for the present, however, we find that various factors, in addition to the cosmic ones named, affect the amount of heat received and retained.

We have seen that the atmosphere absorbs a considerable amount of the heat which passes through it, the amount being reckoned to reach in middle latitudes, even with a clear sky, about 50 per cent. But while the atmosphere thus withdraws a considerable amount of heat, it also acts as a blanket, preventing loss of heat into space. The earth is warmed by the sun's rays and radiates heat into the atmosphere. This radiant heat is largely retained by the atmosphere, chiefly on account of the water vapour, carbon dioxide and impurities contained in the lower strata of air. The blanket effect of moist air is therefore greater than that of dry air, and we thus find that in dry and desert regions radiation is very rapid at sundown, and the sudden drop of temperature is very important in connection with desert weathering (*cf.* p. 61). Similar conditions are present in elevated regions, but to a much more striking extent. Here the air is relatively thin and the density is low. In consequence, while the sun's heat passes through readily, the heat is lost with great rapidity, and there are great differences between sun and shade temperatures, and night and day ones. Generally, as we shall see, elevation affects temperature greatly.

Temperature Conditions over Land and Sea.—Again, another very important factor is the difference in their relation to heat displayed by land and water. The specific heat of the land is only about six-tenths of that of water, or, in other words, if the same amount of heat is received during a given time by unit areas of land and of water, the temperature of the land will be raised nearly twice as much as that of the water. On the other hand, water cools very much more slowly than land. The contrast between the two is increased by the fact that a part of the heat absorbed by

the water is used in evaporating it—at the equator, for example, more than half the heat which falls upon the surface of the sea is used up in the process of evaporation. Still another point is that on land the sun's heat does not penetrate more than 65 feet into the soil, while in the sea, thanks to waves and to convection currents, it penetrates to a depth of 300–650 feet, thus converting the sea into a great magazine of heat. As a result of these facts we find that the sea, as compared with the land, shows small diurnal and small seasonal variations in temperature. Now as the tropics necessarily receive a large amount of heat throughout the year, they are regions where the diurnal variations are great on land and the seasonal small. As the sea heats slowly and cools slowly, the air over it is much cooler during the day than that over the land, and much warmer at night. The result (see p. 218) is to produce the phenomenon of land and sea breezes. In temperate climates the diurnal variations in temperature are not so marked as in the tropics, but the seasonal ones are much greater. Here, therefore, the air over the land is warmer than that over the sea in summer and cooler in winter. Lands near the sea, therefore, and, especially, lands traversed by winds coming from the sea, tend to have a less extreme or *maritime* climate, as compared with lands far removed from sea influences, which show great extremes and have a *continental* climate. This is of great importance in connection with the climates of the populous temperate zones, whose seasonal variations in temperature are largely determined by the extent to which marine influences penetrate. We should notice also that the presence of snow over a land surface diminishes the contrast between land and sea, such a surface being slow to warm up in spring owing to the amount of heat absorbed in melting the snow.

Solar and Physical Climates.—To sum up, the solar or mathematical climate of a place depends upon the amount of heat received by that place from the sun on account of its latitude. If all parts of the globe had a purely solar climate, then the climatic zones would be demarcated by parallels of latitude. In point of fact the climates which do exist are physical or natural climates, the simple theoretical conditions being interfered with, first, by the irregular distribution of land and water over the surface, and the currents, in air and water, produced by this irregular

distribution, and, second, by the surface relief, which not only influences the temperature of the elevated areas, but also has a well-marked indirect effect.

Diurnal Variation of Temperature.—Having thus indicated the nature of the phenomena to be observed, we can pass to details of methods. It follows from what has been already said that at any given place A at a time when this place has, let us say, a fourteen hours' day and a ten hours' night, the temperature will vary from hour to hour as the earth moves, the diurnal temperature increasing to a maximum, and then diminishing till a minimum is reached at the end of the night. Now it is obviously impossible to deal with the mass of figures which would be produced if every meteorological observer recorded hourly or half-hourly temperatures. The averaging of a few daily observations, therefore, in order to obtain a mean daily temperature, obviously presents itself as desirable. The most suitable hours for these observations can only be chosen as a result of experiment. For example, if hourly observations are taken during a considerable period, it is easy to treat these in sets of twos, threes, etc., and so find by trial how nearly such an average agrees with that obtained by adding together the whole twenty-four observations and dividing by 24. According to Hann, the most satisfactory daily mean is obtained by observations made in the early morning, in the afternoon and in the evening, such hours as 7 a.m., 2 a.m. and 9 p.m. being recommended. Another method often employed is to make one reading in the twenty-four hours with a maximum and minimum thermometer, the two readings from this instrument being then averaged. This gives a result slightly in excess of the mean, but near enough for practical purposes; where great accuracy is required a correction is applied.

The reason for the suitability of the three hours named above is found in the diurnal range as shown by hourly observations. Such observations show that the minimum temperature for the twenty-four hours occurs just before sunrise, the earth having then lost much of its heat through radiation. With the rise of the sun above the horizon the temperature begins to rise, the rise continuing till a maximum is reached, not at midday, as might be supposed, but about a couple of hours later. The reason is as follows: Since the dawn the sun has been sending an

increasing amount of heat to the earth, and if there were no loss it might be supposed that the sum would increase until a maximum was attained at sunset. But the temperature at any moment is the result of the relation between the amount of heat received and the amount lost by radiation, and the rate of radiation increases with the temperature. During all the earlier part of the day the total amount of heat received is greater than that lost by radiation; then, with the increasing rapidity of radiation, the amount of heat supplied is just equal to that lost, and from this moment the temperature steadily diminishes.

Mean Annual Temperatures and Isothermal Maps.—By averaging out the diurnal variation in one of the ways mentioned above, we get a figure which is the mean diurnal temperature. By adding together the mean temperatures obtained in this way for all the days of a month, and then dividing by the number of the days of the month, it is possible to obtain a monthly mean. Finally, by adding together the monthly means and dividing by 12 we obtain an annual mean. Monthly and annual means are much more frequently employed in discussing climate than diurnal means, and are frequently represented on maps by means of isothermal lines. The principle which governs the construction of an isothermal map is precisely that which governs the use of contour lines. Thus, to construct a map showing isothermal lines for Britain in January, we first mark upon the map the mean January temperature at all the stations where observations have been made, as at Kew, Edinburgh, and so forth. We next draw lines through those points where the temperature was equal, these lines being isothermal lines. Here, however, a point has to be considered. As we have seen, temperature varies with elevation; therefore in the case of all stations above sea-level a correction has to be applied to reduce the observation to sea-level.

Another point which greatly affects the accuracy of the map is the number of years of observation upon which it has been based. In tropical regions the annual march of temperature appears to be remarkably constant from year to year, but it is otherwise in temperate latitudes. It is calculated that to obtain annual means correct within 0·1° per cent., about forty years of observation are needed in central Europe and about sixty in north-eastern Europe. It

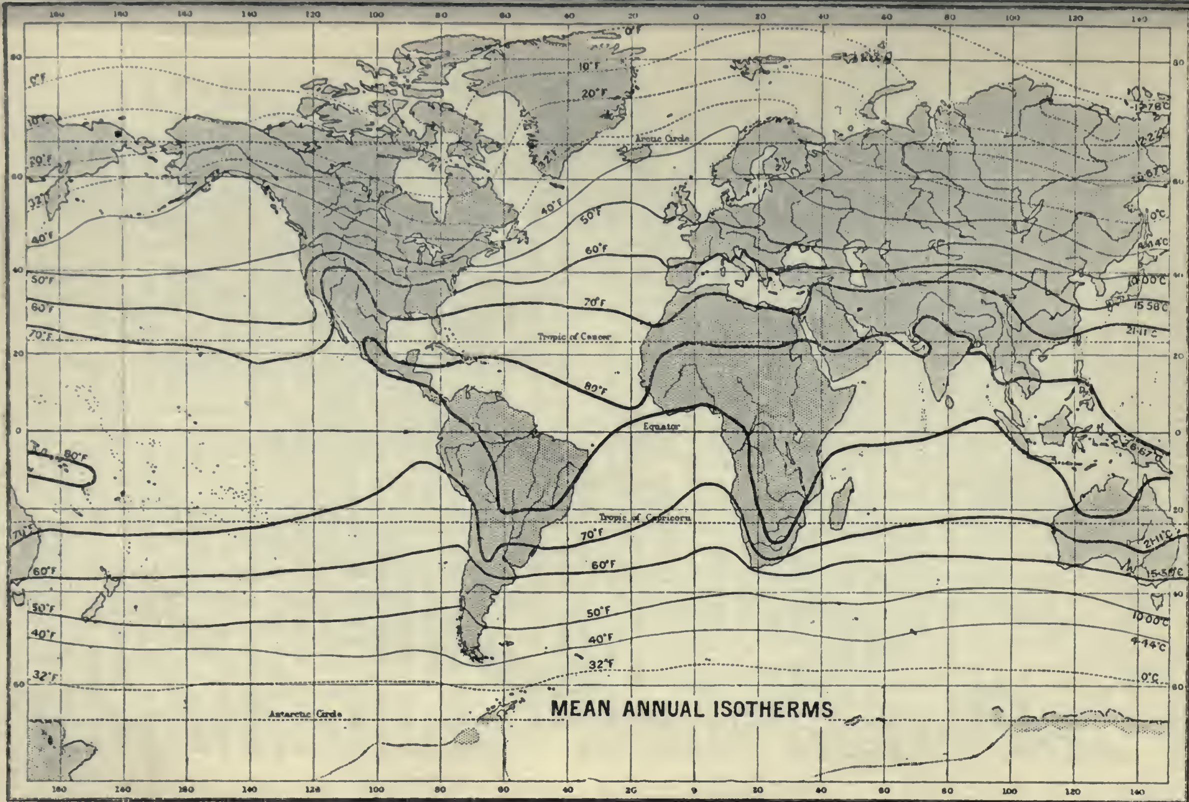


Fig. 68. Mean Annual Isotherms for the Globe. The temperatures are shown both in Centigrade and Fahrenheit degrees. Note the curving of the Isotherms over the oceans, especially in the Atlantic. Up to about lat. 45° the seas are colder than the land, north or south of this they are warmer.

is far more difficult to get perfectly accurate monthly means, for monthly temperatures vary enormously from year to year, and very long series of observations would have to be taken to ensure absolute accuracy; for practical purposes, however, a forty years' mean suffices.

Range of Temperature.—While the mean annual temperature of a place tells us relatively little of its climate, the twelve monthly means, unless they are expressed in the form of a curve, form an unwieldy mass of figures. On the other hand, the January and July means, that is the means of the coldest and warmest months, give us much information about the nature of the climate, the difference between the two giving the mean annual range. For example, when we know that Vienna has a mean January temperature of – 1·5° C. (29·3° F.) and a mean July temperature of 19·8° C. (67·6° F.), while at Aberdeen, placed far further north, the January temperature is 3·1° C. (37·4° F.) and the July 14·1° C. (57·4° F.), we can conclude at once that the former has a continental and the latter a maritime climate.

To sum up, then, the temperatures with which a climatologist deals are all mean temperatures, and represent averages, not observed facts.

Distribution of Temperature over Surface.—We may conclude this section with a brief discussion of the actual distribution of temperature over the surface, as shown by isothermal maps. Fig. 68 is a map showing the annual isotherms over the whole surface of the globe. One of the most interesting points which it illustrates, and one which follows necessarily from what has been already said as to the different specific heat of land and water, is the different position of the isothermal lines on land and over the ocean. The total result both of the difference of specific heat, and of the ocean currents, which chill the warmer seas and warm the colder ones, is that up to about lat. 45° the mean temperature over the sea is lower than that over the land; while from 45° to the poles the seas are warmer than the lands. The resultant curving of the isotherms should be carefully noted on the map. Another point of great interest is the position of the isotherms in relation to latitude in the two hemispheres. The student should pick out a few isotherms and carefully note their relation to the lines of latitude in the northern and southern hemisphere. In more detail, it is possible to calculate from the map the mean

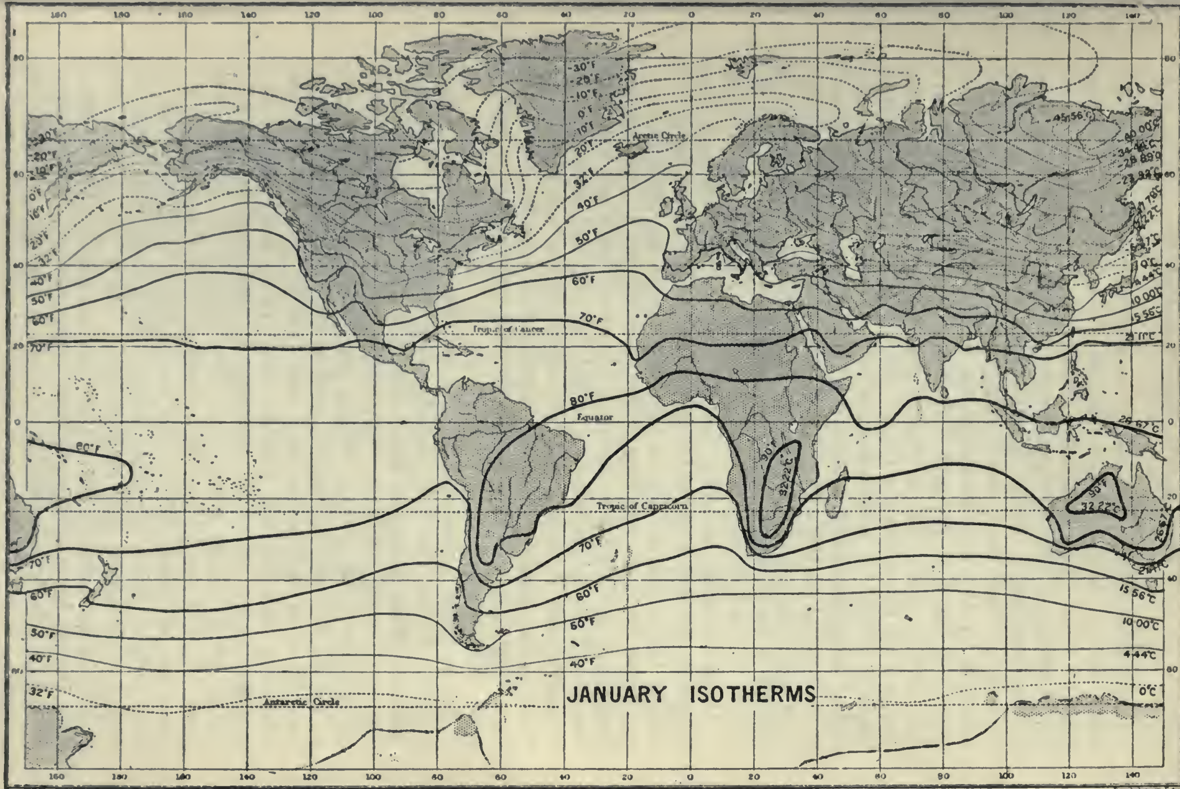


Fig. 69. Mean January Isotherms for the Globe. In the northern hemisphere the oceans are warmer than the lands.

temperature in any latitude, a number of equidistant points being taken along the line selected. It is possible in this way to show that from the equator to lat. 45° the mean temperature of the northern hemisphere is higher than that of the southern. South of this parallel the conditions are reversed. Now there is no difference in the amount of heat received by the two hemispheres, and the difference is due primarily to the unequal distribution of land and water. As already seen the southern hemisphere contains more water than the northern (*cf.* p. 23). As the slightly greater warmth of the far southern seas does not compensate for the lower temperature of those lying further north, as compared with the seas on the other side of the equator, it is calculated that while the mean temperature of the whole globe is 15° C. (59° F.), that of the southern hemisphere is only 14·6° C. (58·3° F.), while that of the northern is 15·4° C. (59·7° F.).

If on the map showing annual isotherms we draw a line between the two highest isotherms (80° F.), and continue it across the ocean so that it passes through the highest temperatures on each meridian, then we shall get a line—not an isotherm, for it passes through places of different temperatures—which forms what is called the thermal equator. It is easily seen from the map that this thermal equator is far from corresponding to the geographical equator; it is an imaginary line which is of considerable importance in dealing with climatic problems.

As we have already seen, the annual temperature is less important than the July and January means, and the maps showing these illustrate some interesting points. In the map for January (Fig. 69) the position of the line marked 0° C. or 32° F. should be noted. While, generally speaking, it bends to the north over the oceans and to the south over the continents, it is noticeable that the western coast of Europe, including the British Islands and, to a less extent, the western coast of North America, lie well within it, or in other words these regions are far warmer in winter than their latitude would lead us to expect. To the north of the very sinuous line of 0° C. the mean January temperature is everywhere below freezing-point, the lowest temperatures being enclosed in the isotherm of $-45·6°$ C. ($-50°$ F.), which is remarkably dissymmetrical in relation to the pole. The lowest known mean winter temperatures do not occur near the pole but in Siberia, the mean January temperature

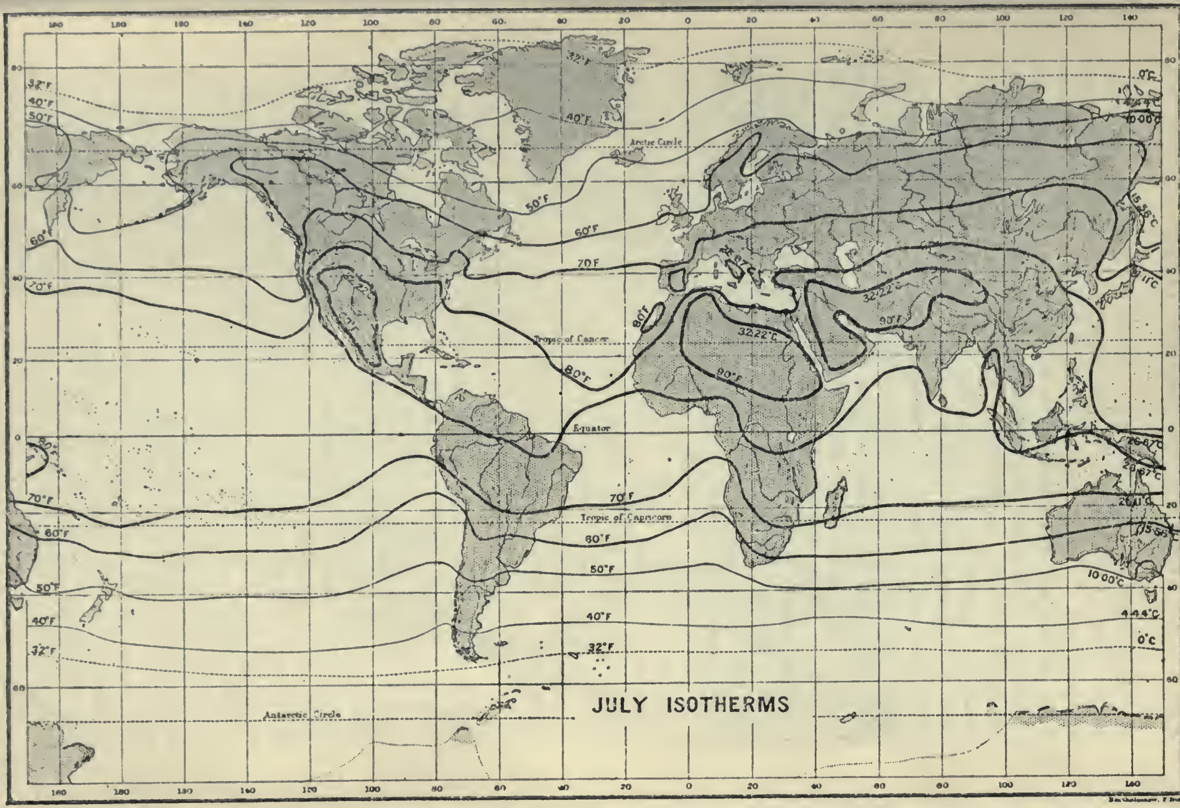


Fig. 70. Mean July Isotherms for the Globe. In the northern hemisphere the lands are warmer than the oceans.

at Irkutsk being – 42·8° C. (– 45° F.). The coldest place on the globe in winter is Verkoyansk, with a mean January temperature of –49° C. (– 56° F.), but the position of this town at the bottom of a shut-in valley makes its temperature conditions somewhat exceptional. It is interesting to note the extraordinary variations of temperature found in January along the Arctic Circle; along this line we have temperatures of 2° C. on the coasts of Norway and – 49° C. in Siberia.

As the map shows, in January in the northern hemisphere the lands are everywhere colder than the seas in the same latitude, but in the summer the conditions are reversed. In July three areas have mean temperatures exceeding 32° C. (90° F.). These are situated one in the north of Mexico and the south-east of the United States, another in Central Asia, Persia, Arabia, the third in the Sahara and part of the Sudan. The absolute maximum is reached in the Sahara, where the July mean exceeds 35° C. (95° F.).

CHAPTER XIV

PRESSURE AND WIND

Measurement of Atmospheric Pressure.—Variations in Pressure, Diurnal and Annual.—Wind.—Measurement of its Force.—Its Cause.—Direction of Winds.—Ferrel's Law.—Buys Ballot's Law.—Cyclones and Anti-cyclones.—The Planetary Circulation.—Prevailing Winds.—Land and Sea Breezes.

ATMOSPHERIC PRESSURE is the elastic force exercised by a given mass of air, and it is usually measured by the height of the column of mercury which the air will support. The instrument by means of which this measurement is effected is called a barometer. The principle of this instrument is exceedingly simple. If we take a uniform glass tube, some three feet long, completely fill it with mercury, and then invert it, closing the open mouth of the tube meanwhile with the finger, and place this open end beneath the surface of a quantity of mercury in a basin, we shall find that the mercury column sinks, leaving a vacuum above. The height of the column depends (1) upon the temperature at the moment of the experiment, (2) on the height above sea-level of the place where the experiment is performed, and (3) upon the atmospheric pressure, which varies from day to day and even from hour to hour. Now obviously it is possible to eliminate (1) and (2) by calculation, and we have then an instrument which will register the variations of (3).

The actual barometer is necessarily a more complicated instrument, but the principle remains the same—that above the mercury column there is a vacuum, and that the atmosphere exercises a certain pressure upon the mercury in the basin, that pressure being measured by the height of the column of mercury, at sea-level and at a temperature of 0° C. or 32° F., the last condition being necessary to eliminate the error caused by the fact that mercury expands, and therefore changes in density with the temperature. In order to measure the height of the column a scale must be added, which is graduated either in inches or in centimetres. To it a vernier is usually attached to permit of the making of accurate readings.

Although the mercury barometer is the only precise instrument by which pressure variations can be measured, yet it has the great disadvantage of being difficult to carry about. Travellers therefore usually rely upon an aneroid, which in essence consists of a metallic box with flexible walls, containing a vacuum. The wall of the box is affected by the varying atmospheric pressure, and its movements are communicated to a needle, which moves round a dial. Aneroid barometers are liable to change with time, and they never give such precise figures as the mercury barometer, but they are very portable, and are especially useful in indicating considerable variations in pressure, such as, for example, occur on ascending a hill or mountain. They are also used to measure the height of a mountain, for the pressure naturally diminishes as we ascend above sea-level, and the amount of the diminution, at any given point, gives us a measure of the amount of the ascent (*cf.* p. 32).

Variations in Pressure. (1) *Diurnal.*—The mean pressure of the atmosphere, as measured by the barometer, is 760 mm. or 30 inches, but considerable variation occurs. There is first of all a diurnal variation, which is associated with the diurnal variation in temperature, but is very much less obvious. In temperate latitudes the diurnal variation can only be made out by very close observation; in tropical regions it is, however, comparatively easy to see that there is a morning and night maximum, with intervening minima, giving rise to a double curve. This has, however, no practical importance.

Pressures considerably above the mean are called High, those considerably below, Low.

(2) *Annual variations* are, as contrasted with diurnal ones, of great importance, and differ greatly in different parts of the globe; in this case, as with temperature, mean results are obtained by averaging a great number of observations. In middle latitudes the pressure is high in winter and low in summer over the great continents, while over the oceans the conditions are reversed. This is obviously the effect of the different specific heats of land and sea to which reference has been already made. In summer the interior of the great continents heats up rapidly, and the air above the heated surface expands and rises producing a fall of pressure which, as we shall see, sucks in air from adjacent regions. In winter the rapid cooling of the land cools the air above,

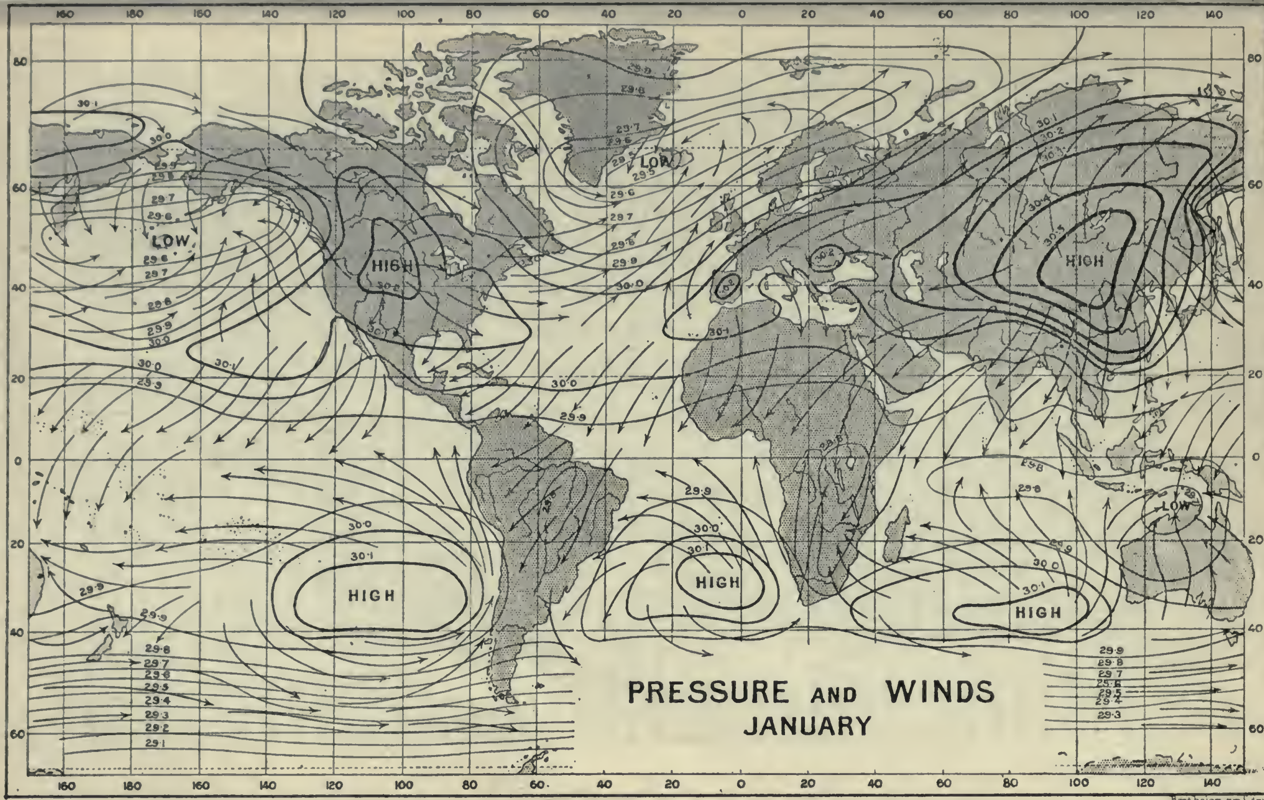


Fig. 71. Mean Pressure and Winds for January. In the northern hemisphere the pressure is high over the continents and low over the oceans. In the southern hemisphere it is high over the oceans.

which thus becomes heavier as it contracts. The sea, alike slow to heat and slow to cool, receives in summer the outflowing air from the lands, while in winter the air, warmer above it than above the lands, flows landwards, thus lowering the pressure over the sea. Thus at Moscow the highest mean monthly pressure is in January, the lowest in June, while in the Azores the conditions are reversed, the highest pressure being in July and the lowest in November. Places near the margins of the great oceans, such as Paris or London, show an intermediate condition, being continental in winter and maritime in summer. Thus Paris has two maxima, one in winter and one in summer, and two minima, in spring and autumn respectively, and the same conditions prevail in London.

More complicated are the pressure variations over the globe in general. The mean conditions for any period, annual or monthly, are most conveniently represented on a map by lines, called isobars, which are drawn through places where the mean pressure is the same for the period selected. The principle is thus the same as for isotherms. In such maps not only must all observations be corrected for altitude and temperature, but also an allowance must be made for gravity, which varies from latitude to latitude. The accompanying maps (Figs. 71 and 72), representing the isobars of the globe for the months of January and July, show the main points in regard to the distribution of pressure. From the first we see that round the equator there is a well-marked belt of low pressure, *i. e.* below 760 mm. or 30 in., obviously the result of the temperature conditions which reign here. On either side of this zone, in the tropics, lie belts of high pressure, that is regions where the mean pressure exceeds 760 mm. Within this high-pressure belt exist regions of maximum pressure, the most important of which for the climate of Europe is that round the Azores, where the mean pressure is over 30·1 in. Beyond the tropical high-pressure belt the pressure diminishes rapidly, more steadily towards the south than towards the north, owing to the fact that the former region has less land to introduce disturbances. Within these low-pressure areas occur minima, of which the most important is that in the Atlantic near Greenland, where the pressure is below 29·5 in. As we shall see, these irregularities of pressure distribution, like the irregularities of temperature distribution

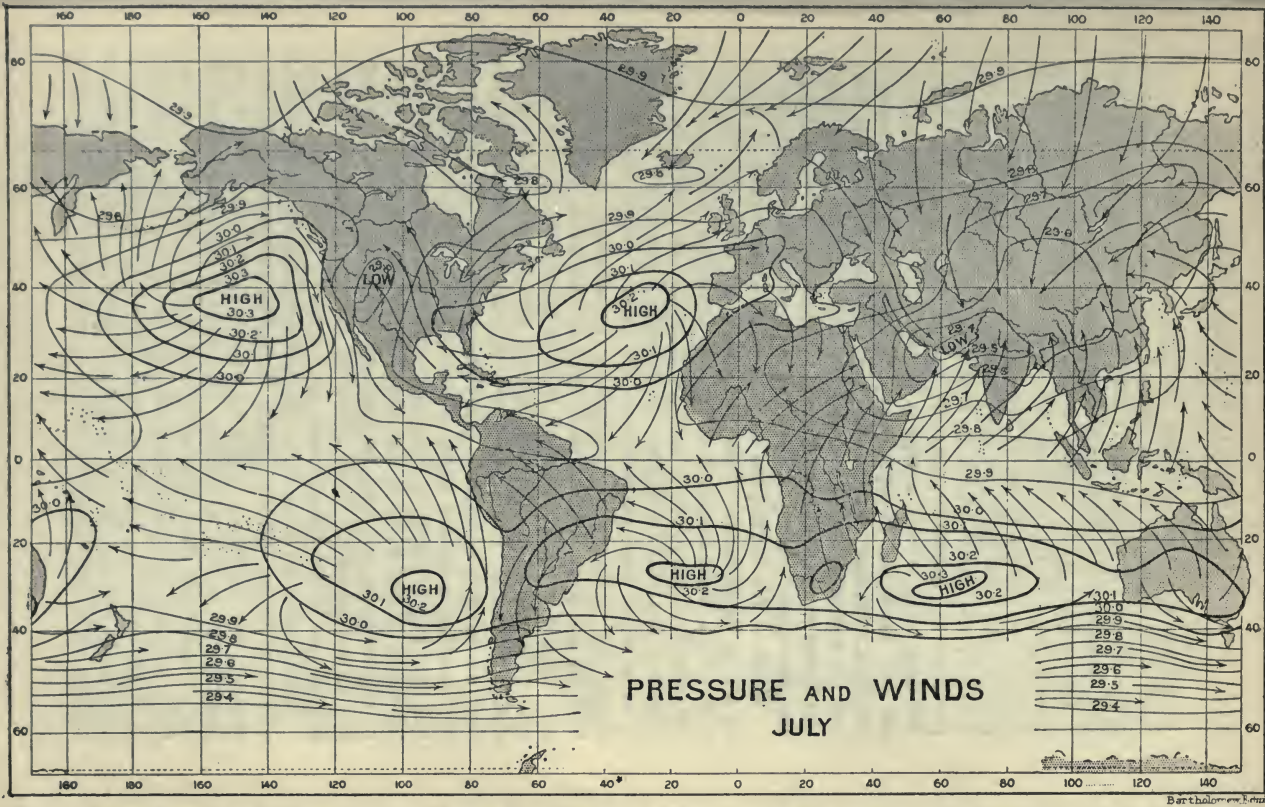


Fig. 72. Mean Pressure and Winds for July. Note both in this and in Fig. 71 the great constancy of the westerly winds in the southern hemisphere. They form the *Brave Westerlies*, and the latitudes in which they occur are called the *Roaring Forties*.

to which they are related, are due to the distribution of land and water over the globe, and the different specific heats of land and water. Without these disturbing features the isobars would run regularly round the globe.

In comparing the isobars for January and July, the interesting point is the shift of the equatorial low-pressure belt. As the sun moves south of the equator the low-pressure belt moves also; as he turns northwards again after the winter solstice, the zone which is most highly heated and where pressure is, therefore, lowest, moves with him. In detail we note that where a region is excessively cold in winter, as, for example, in north-eastern Asia, there the pressure reaches a winter maximum; where a region becomes very hot in summer, as, for instance, the south of Asia, there the pressure becomes minimal. Anomalies of temperature are, therefore, closely associated with anomalies of pressure.

Wind.—We must pass next to the consideration of wind, or air in movement. This movement always takes place in a direction little removed from the horizontal, and therefore for practical purposes it may be regarded as horizontal; the direction is always indicated by the side from which it comes, thus a west wind comes *from* the west. With ocean currents the contrary nomenclature is adopted, a westward current being one which is flowing *to* the west. The direction of the wind is obtained from a weathercock, the more elaborate forms of this instrument being connected with a dial within the building to which they are attached, the dial showing the sixteen principal points of the compass, and bearing a needle hand which points to the direction of the wind prevailing at the moment. The question of the direction of the wind is the most important theoretical point in regard to it, and various methods are adopted for showing the directions which have prevailed over given periods, forming the so-called wind-roses.

The Force of the Wind is measured by an anemometer, which gives an actual figure, in miles per hour or feet or metres per second. Where, as on board ship, such an instrument is not available, the wind's force is estimated on a scale (the Beaufort scale) which runs from 0, a calm, that is when the wind does not exceed 1 metre a second or 2 miles an hour, to 12, a gale, when it is more than 30 metres a second or 67 miles an hour. The intervening figures have intervening values. On weather charts (*cf.*

Figs. 87, 90, 91, 92) four types of arrows are employed, indicating respectively a force of from 1–3, from 4–7, from 8–10, and from 10 upwards on the Beaufort scale. It is noticeable that the force of the wind increases with distance from the ground—a common fact of observation when towers, etc., are ascended. This is due to the fact that nearer the ground the free movement of the air is impeded by many obstacles, such as trees, buildings, etc. In towns the presence of buildings often gives rise to peculiar currents and eddies, which make weathercocks give deceptive indications, unless they are well above surrounding buildings.

CAUSE OF WIND.—The ultimate cause of wind is to be sought in differences of temperature which produce changes of pressure. The two diagrams, Figs. 73 and 74, illustrate

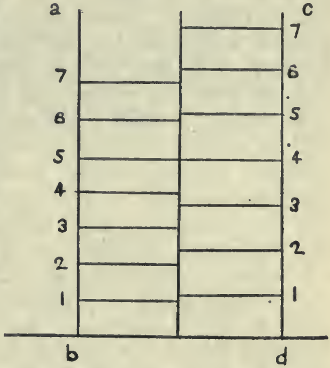


Fig. 73. Cause of Wind. (Fo explanation see text.)

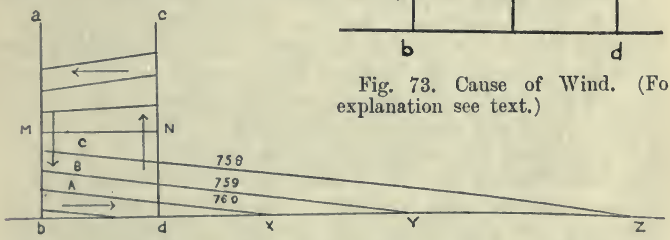


Fig. 74. Cause of Wind. (For explanation see text.)

this. Let *ab* and *cd* represent two columns of air separated by an air-tight partition. Apply heat to *cd*, the temperature of *ab* being kept constant. The figures indicate successive strata of air of equal pressure, the pressure necessarily diminishing as we ascend from 1 to 2, 3, 4, etc. The heating causes the strata in *cd* to expand, so that the whole column increases in height, and the pressure therefore increases in the upper part of the column *cd*. Now remove the partition (Fig. 74). As the pressure in the upper parts of *cd* is greater than at the same height in *ab*, there

will be a flow of air towards *a*. As a result the pressure diminishes in *cd* and increases in *ab*, so that the pressure becomes greater at *b* than at *d*. Therefore air flows from *b* to *d*. If the temperature be kept steady in *cd*, a regular current of air will take place in the directions indicated by the arrows in Fig. 74. But as the pressure is greater at *c* than at *a* and less at *d* than at *b*, there must be a region, shown by the horizontal plane MN, where the pressure is equal throughout. Above this neutral plane the pressure diminishes from right to left and the air follows the diminution of pressure; below it the pressure diminishes from left to right, and again the air follows the line of least resistance. Further, it is easy to see that the result is the same if we suppose that the column *cd* is warmed, or that the column *ab* is cooled; in both cases air near the surface of the ground will be drawn from the cool area to the warmer one, a reversed current taking place in the upper layers of the atmosphere, and vertical currents completing the circuit. The only deceptive point about the diagram is that in nature the horizontal distance *bd* is enormous as compared with the vertical distance *ab* or *cd*.

One other point may be brought out by the diagram. The lines A, B, C obviously indicate the position of planes of pressure, that is of isobaric surfaces, and we note that they slope from the colder towards the warmer region. If we prolong the horizontal line *bd* corresponding to the surface of the ground and also prolong the lines A, B and C, we find that they meet the horizontal plane in points X, Y and Z (Fig. 74). We see that X, Y and Z are points where isobaric surfaces intersect the surface of the earth at sea-level, and that they are also points on isobars. We thus find that isobars are simply the intersection of planes of equal pressure with the surface of the ground. Now the strength of the current from *b* to *d* depends upon the inclination of the isobaric surfaces, that is upon the distances between X and Y, Y and Z, and so forth. The difference in pressure between X and Y being by definition 1 mm., let the distance XY be 100 kilometres. Then we may say that there is a barometric gradient of 1 mm. in 100 kilometres. The closer the isobars are together, that is the smaller is the distance XY, the greater the force of the current, which is always proportional to the gradient. Thus just as we know that when in a contoured map the contour lines are close together

the slopes are steep, so we know that when on a pressure map the isobars are near, then the winds will be strong. On the other hand, when they are far apart the gradient is slight and the current will be correspondingly gentle.

Direction of Winds: Ferrel's Law.—We might suppose from what has just been said that when we look at a map and find that the pressure gradient is, let us say, from south to north, then we could assume at once that the wind would be from south to north. But here another element intervenes. As we have seen, the earth is a rotating body and is, speaking generally, spherical. Therefore a moving particle of air at the equator has a longer course to cover as the earth rotates than a particle nearer the poles, and as the time of rotation is the same in all cases, such a particle must move faster. When such a particle moves northwards, therefore, it retains its greater velocity and travels faster than the earth in this latitude. It is, therefore, apparently deflected towards the east or right hand. This is Ferrel's law, already alluded to (see p. 91). Its result in this case is that the wind is always inclined to the gradient, the inclination being to the right in the northern hemisphere and to the left in the southern. The same thing happens with currents, but in the case of water the friction of the particles is very great, and the amount of deflection, even in high latitudes, is relatively slight. In the case of air the friction is small and in higher latitudes the deviation is consequently very much greater, so that the wind, instead of blowing at right-angles to the isobars, tends to blow along them (see Fig. 89).

Buys Ballot's Law.—In consequence of this fact we can tell something of the distribution of pressure merely by knowing the direction of the wind. If an observer stand with his back to the wind, then in the northern hemisphere the area of lower pressure will be on his left hand and the higher on his right. This useful generalisation is known as Buys Ballot's law.

Cyclones and Anticyclones.—In the case already discussed we have supposed that the isobars take the form of straight lines parallel to one another, but other types of distribution of pressure exist. We find in some cases that the pressure either increases or decreases in all directions from a central point, and in this case the isobars form concentric lines, the gradient being either from a margin of

high pressure to a central point where the pressure is low or outwards from a centre of high pressure. The first condition is described as cyclonic, the second as anticyclonic. From Buys Ballot's law it is easy to see that in the northern hemisphere the winds will sweep into the central low pressure area of a cyclone in a counter-clockwise direction, while in the southern hemisphere they will have the same direction as the hands of a clock, or will be clockwise. With an anticyclone the much gentler air currents take the reverse direction in sweeping out from the centre, being clockwise in the northern hemisphere.

These wind swirls obviously depend upon the fact which we have just discussed that the effect of the rotation of the earth is to produce a deflection of the wind. In consequence cyclones cannot occur at the equator, for there the deflecting force of the earth's rotation is nil. As we have seen, the deflection increases with the latitude, and in the same latitude the angle between the wind and the barometric gradient increases with the diminution of friction. Thus cyclonic movements will be greater in high latitudes than in low, and better marked over the sea, where the friction is small, than over land where it is greater.

In a cyclonic area, as we have seen, the air is swinging towards the centre from all sides. But if the central low-pressure area is to persist, then the air thus entering must find a way of escape. This it does in the upward direction, so that a cyclone may be described as an area of low pressure from which currents of air are ascending in spirals. By a parity of reasoning we can see that in an anticyclone we must have descending currents of air. As we shall see later these facts have a good deal to do with weather, for they influence greatly precipitation of moisture.

The causation of the two types of pressure systems is a difficult matter. We may note that if in Fig. 74, instead of parallel columns of air, we have a warm centre surrounded by a colder area, then currents of air would swing in from all directions to this warm region, and below the neutral plane a cyclonic area will be produced from which an upward current will escape. Above the neutral plane the circulation will be reversed, the currents swinging out of the area, so that an anticyclone will be present. The heating of a given centre should thus give rise to a cyclone, and conversely the cooling of a given area should give rise to an anticyclonic

condition. Not all cyclones and anticyclones, however, are produced in this way, and, indeed, those so produced seem to be rare. Without going into this difficult subject in detail, it may be noted that it appears that as a result of the planetary circulation the atmosphere tends to show stratification into warmer and cooler layers. If a warm layer lie beneath a cool one, then the atmosphere becomes unstable, and the lower layer may break through the upper in the form of a violent upward current. Except in very low latitudes this upward current may give rise to a cyclone. The conditions are thus far more complicated than is suggested in Fig. 74, cyclones and anticyclones being really eddies in the great air movements.

The Planetary Circulation.—After the discussion of these general points we may turn now to the main facts as regards the circulation of the atmosphere. As in the case of temperature and pressure, in order to understand the existing conditions we must take first a theoretical globe, with the sun always over the equator and no disturbance due to the irregular distribution of sea and land. In that case right round the equator we should have a band of heated air, where the pressure is low, and in consequence where there is a gentle rising current of air towards the upper strata, and compensating currents from the north and south in the lower strata. The total result should be as shown in Fig. 74, and we should, therefore, find, if *d* represent the equator and *b* a point in the northern tropic, that in the lower strata of the atmosphere a north wind blows towards the equator, and in the upper strata a south wind blows towards the northern tropic. But here the rotation of the earth introduces its deflecting effect, turning in the northern hemisphere the lower current into a north-east wind, and the upper into a south-west wind. In the southern hemisphere the currents are reversed. Now the lower winds, well developed over the oceans, blow with such regularity that, as is well known, they are called trade winds, while the upper currents are the counter trades or return trades. So far all are agreed; what follows is rather more uncertain and disputed. As the counter trades reach higher and higher latitudes the deflecting effect of the earth's rotation increases, and at the heights in the air at which they blow the effect of friction is minimal. Thus the wind loses more and more its poleward direction, and comes to blow practically from the west, with a force

superior to that of the earth's rotation. This happens between lats. 30° and 40° N. (and at the same latitudes in the southern hemisphere). Owing to the almost circular direction of movement and the high velocity a powerful centrifugal force is set up here, with the result that we have a zone of maximum pressure, from which the air is forced out both towards the poles and towards the equator. Thus in these middle latitudes two contrary effects are produced. If temperature alone were concerned, then pressure should increase steadily from the equator to the poles. But the effect of the wind swirl just described is to tend to force the air away from the poles towards the equator. The result of the two tendencies is to give the distribution of pressure already described, and in consequence to make the sub-tropical belt of maximum pressure an area of descending currents, and therefore one of great dryness; it includes nearly all the deserts of the globe. From these pressure conditions the planetary winds arise, which are as follows: At the equator (Fig. 75) reigns a belt of calms, the doldrums, with ascending currents, and therefore copious precipitation; to north and south of this comes the zone of the trade winds, blowing from the north-east in the northern hemisphere and south-east in the southern. Further north and south comes the belt of maximum pressure, which is also a region of calms, and forms the horse latitudes, but is dry because of the descending currents which compensate for the equatorial updraught. To the north and south of this we have a low-pressure zone where the stormy westerlies prevail, generally south-west in the northern hemisphere and north-westerly in the southern; but both belts are regions where storms are frequent, and the westerly component increases in each case

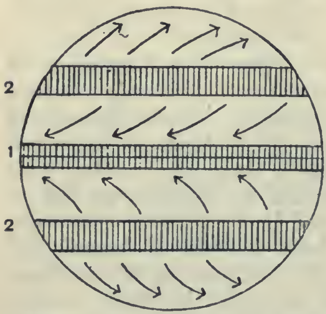


Fig. 75. Diagram to show the planetary winds at the surface.
(1) The low-pressure equatorial calms, or doldrums. (2) The high-pressure calms or horse latitudes. Towards the equator blow the trade winds, while in higher latitudes than (2) we have the prevailing westerlies, strongest in the south (see Fig. 72).

as we approach the pole, where the pressure begins to rise again. Such a system of winds would develop on any rotating planet with an atmosphere, and is therefore called the planetary system. The special characters of the earth introduce considerable modification, which make the actual winds much more complicated than the scheme would suggest.

Prevailing Winds.—The first modification is due to the fact that up to a latitude of 45° the mean temperature of the continents is higher than that of the seas. Necessarily, therefore, the belt of high pressure which should encircle the globe in lat. 30°–35° will be interrupted, for the heated continents produce regions of low pressure above them in summer, while at the same time the pressure is augmented over the Atlantic. Now, as we have already seen, all regions where the isobars have a concentric form give rise to the cyclonic or anticyclonic type of circulation. This, as the maps forming Figs. 71 and 72 show, greatly modifies the actual conditions as compared with the theoretical ones shown in Fig. 75.

The second modification is due to the fact that the geographical equator does not correspond throughout the year with the thermal equator. As the sun moves north or south of the equator it carries with it the equatorial low-pressure belt, and thus the accompanying winds all experience a shift, to the north or south as the case may be. This is especially marked in the case of the regular trade winds, which change in position with the seasons.

But while the effect of the seasons is marked in connection with the trades, it is infinitely more striking in connection with certain other winds which, on account of their complete reversal with the seasons, are called the monsoons. It is obvious from all that has been already said that large continents must act as heat centres in summer and as cold centres in winter. Thus, if the general circulation of the atmosphere did not exist, we should get a cyclonic régime over the continents in summer and an anticyclonic one in winter, the reverse conditions occurring over the oceans. This tendency exists everywhere, but under most circumstances the general circulation is strong enough to prevent it being very obvious, the difference between the summer and winter temperatures in the interior of the continents not being large enough to effect greatly the winds due to the

ordinary circulation. There is, however, one great exception. The great continent of Asia, as already indicated, is remarkable for the extreme lowness of its winter temperatures, in relation to latitude, and at the same time for the very high pressure. In winter, therefore, this continent is the seat of a vast anticyclonic movement, the winds sweeping out from the land to the sea (see Fig. 71). This movement appears off the south-east of Asia as a reinforcement of the north-east trade, and owing to this reinforcement this wind is able to cross the equator and extend into the region of calms. It is necessarily deflected to the left on the other side of the equator, and therefore appears in the southern part of the Indian Ocean as a north-west wind.

In summer, again, a cyclonic circulation develops over Asia, and we have a south-west monsoon, strong enough to overcome completely the normal trade wind in the Indian Ocean (see Fig. 72). This monsoon is much stronger than the winter monsoon, for the differences between sea temperatures and land temperatures are much greater in summer than in winter.

Though monsoons on the large scale only occur in the case of Asia, yet the monsoon effect is visible in connection with many other continents, where it introduces modifications in the local and seasonal distribution of the winds.

Land and Sea Breezes.—We have already noted that the temperature curve varies not only from season to season, but also from hour to hour as the earth rotates. Obviously, then, there ought to be a diurnal variation in the wind, comparable to the seasonal monsoon effect. This is seen in the alternation of land and sea breezes. The land heats more quickly than the sea; therefore at places on the sea-shore a cool breeze should blow from the sea to the shore during the hottest hours of the day. But the land cools more quickly than the sea; therefore after sundown, when the land is cooling rapidly, a current of air should set in from the land to the sea—the land breeze. Between the periods when the opposing winds blow there should be a period of calm.

Just as in the case of monsoons, so in the case of land and sea breezes the general circulation is often strong enough to mask the alternating effect. The sea and land breezes, other things being equal, will tend to be stronger in the tropics than in temperate latitudes; they will tend to be stronger where the effect of ocean currents increases the

temperature contrast between land and sea than where they tend to diminish them. Thus we find that these breezes are very striking off the west coast of Africa, where the coast is washed by cold currents (*cf.* Chap. XIX.). Further, as the currents are reversed by night and day, in a region where a more or less constant wind blows one of the breezes will tend to be reinforced by the ordinary circulation, and one to be neutralised by it; thus the one will be violent and the other scarcely visible. This is very noticeable off the coast of Chili, where the prevailing wind is south-west. The sea breeze has the same direction, with the result that during the day there is often a violent wind, while at night when the land breeze blows from the north-east there is a calm.

Conditions comparable to those giving rise to land and sea breezes occur in mountain regions, especially where there are long, narrow valleys. Here in summer and in fine weather a breeze often blows steadily up the valley during the day and down it during the night, the cause being again unequal heating and cooling of the air.

CHAPTER XV

ATMOSPHERIC MOISTURE AND PRECIPITATION

Sources of Atmospheric Moisture.—Absolute and Relative Humidity.—Dew-point.—Variations in Humidity.—Condensation and its Causes.—Clouds.—Rain.—Distribution of Precipitation over the Surface.—Seasons of Rainfall.

Of all the meteorological elements perhaps the most important to man is the amount of moisture in the air and the precipitation. The atmospheric humidity has a considerable direct physiological effect, and, further, it exercises an enormous influence on the products of any given region, and therefore on its suitability for man's activities.

Source of Atmospheric Moisture.—We must first consider briefly the source of atmospheric moisture. The breathing of animals, the process of transpiration of plants, both supply considerable amounts of water vapour to the atmosphere; but these amounts are insignificant compared to the enormous quantity furnished by direct evaporation from the surfaces of the oceans, lakes, rivers, etc. The amount of this evaporation can be directly measured by observation of the amount of diminution suffered by a given volume of water exposed to the atmosphere during a given time, but all such observations are subject to considerable mechanical difficulties, and meteorologists devote attention rather to the measurement of the amount of moisture in the air than to the rate of evaporation. Certain general facts are, however, clear; the experiences of daily life show us that evaporation increases with the temperature and with the velocity of the wind, and diminishes with increasing humidity of the air and also, though this is less obvious, with a diminution of pressure.

The moisture supplied to the air by evaporation is disseminated partly by slow diffusion and partly by the wind. It is important, from many points of view, to be able to measure the amount present in any given volume of air. To make clear the different methods adopted to achieve this

end we must first distinguish between relative and absolute humidity, of which the first, from the point of view of our sensations, is by far the most important.

Absolute Humidity.—Water vapour is a gas, and, like other gases, possesses elastic force. Now air, unless artificially dried, always contains a greater or smaller amount of moisture, and the air pressure, as measured by a barometer, is the result of the pressure exerted by the air plus the pressure exerted by the amount of water vapour present. Thus, if we place a barometer in a closed space containing ordinary atmospheric air, and then dry this air, or replace it by dried air, we shall find that the barometer falls slightly, the fall being due to the withdrawal of the water vapour, and affording a measure of the amount of vapour which was present previously. This is the *absolute humidity* of the air, *i. e.* its actual content of water vapour. If the temperature be kept constant we find that by no device can the absolute humidity be increased beyond a certain point; at this point

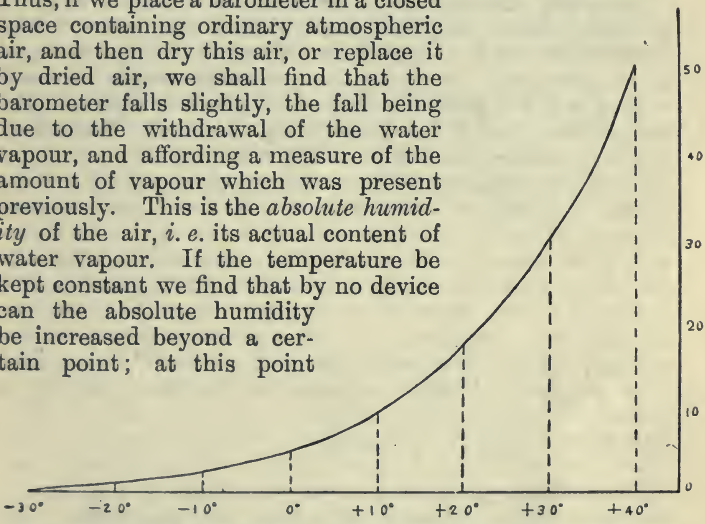


Fig. 76. The maximum weight of water vapour which can be contained in a cubic metre of air at different temperatures.

The horizontal figures are temperatures in degrees Centigrade, the vertical ones weights in grammes. Note the steepening of the curve with rising temperatures.

the water vapour exercises its maximum pressure, and the air is said to be *saturated*. This maximum elastic force has been measured at all temperatures, and from it, by a simple physical calculation, it is possible to find the weight of water vapour in a given quantity of air. At a temperature of 0° C. the maximum weight of water vapour which can be contained in a cubic metre of air is 4·84 grammes, and this vapour exercises a pressure of 4·57 mm.

of mercury. By raising the temperature 10° the pressure is increased to 9·14 mm. and the weight of water vapour to 9·33 grammes, while if the temperature is lowered to −10° the maximum pressure is only 2·15 mm. and the weight 2·36 grammes. Thus, while the weight of water vapour which will saturate a given quantity of air varies with the temperature, it does not, as the figures show, vary uniformly, for it increases more rapidly at the higher temperatures than at the low (see Fig. 76).

RELATIVE HUMIDITY.—If air which is saturated at 0° C. be cooled below this point, then condensation occurs, while, on the other hand, if it be heated above 0° C., then it ceases to be saturated. If H be the maximum weight of water vapour which a given quantity of air can contain at a given temperature, and h be the quantity it actually contains at this temperature, then h/H is the *relative humidity*, or the ratio of the weight present to the maximum weight possible at this temperature. Similarly, if P be the maximum pressure which could be exerted by the water vapour contained in a given quantity of air at a given temperature, and p be the actual pressure of the amount of water vapour present, then p/P is also the relative humidity. Instead of expressing this by a fraction, it is usual to express it as a percentage. Thus, if a cubic metre of air at 0° C. contains 2·42 grammes of water vapour, the relative humidity is 50 per cent. $\left(\frac{2\cdot42}{4\cdot84} = \frac{1}{2} \times 100\right)$.

DEW-POINT.—Another method of indicating the amount of water vapour present is to give the dew-point. Any volume of air containing water vapour will deposit a part of this vapour as moisture if it be cooled sufficiently. The temperature at which a first condensation of moisture is observable, the so-called dew-point, affords a measure of the amount of water vapour present, for obviously the point at which condensation just begins is saturation-point, and by looking up in a table the maximum pressure for this temperature can be found directly. This dew-point method is the best method of obtaining the humidity, relative or absolute, one of the most effective instruments for the purpose being Dines' hygrometer; but dew-point observations demand time and care. Therefore, in most meteorological stations wet and dry bulb thermometer observations are

made instead. In this case two precisely similar thermometers are mounted beside one another, the one having its bulb kept permanently moist by being surrounded with a piece of muslin placed in connection with a vessel of water by a cotton wick. Evaporation takes place from the muslin at varying rates according to the weather, and therefore the wet bulb instrument always gives a lower reading than the dry one. The two instruments are read at the same time, and it is possible to calculate by means of a formula the humidity of the air from the two observations. In point of fact, however, this is obtained directly, *i. e.* without calculation, from tables constructed on the basis of a long series of dew-point observations.

VARIATIONS IN HUMIDITY.—Like the other climatic factors, the humidity shows for the same place both a diurnal and an annual variation, and it also varies from place to place over the surface of the globe. In the most general way we may say that the absolute humidity varies with the temperature. Thus it is greater in the warmer parts of the globe than in the colder, greater during the day than at night, greater during summer than in winter, and so on. This is, however, only a general statement, for in particular cases other factors intervene. Thus in temperate latitudes in winter there is an absolute minimum before the dawn and an absolute maximum during the warmest part of the day; but in summer there is a second minimum during the hottest hours of the day, and two maxima, one in the morning and one in the afternoon. This is due to the fact that in summer, as already seen, there are strong ascending currents of air during the hottest hours of the day, and these carry the water vapour up with them, while cooler and drier air takes the place of the warm moist air which has been carried away in these currents.

As regards the annual variation, we find that this is minimal in hot climates of the maritime type, where the air contains much water vapour at all seasons. Thus at Batavia the mean annual absolute humidity, when measured by a mercury column, is 20 mm. (·8 in.), and the difference between the maximum and minimum is only 2 mm. (·08 in.), whereas in temperate climates a difference of 6 mm. (·2 in.) may occur. The highest maximum figures for absolute humidity are found in equatorial regions, where the maximum follows the sun in its movements. Here the figures

may rise to 20–25 mm. (·8–1·0 in.). Passing north and south of the equator we find that the maximum figure diminishes, the absolute minimum being reached in winter in the interior of the great continents, *e.g.* in Siberia and the far north of America the January minimum is below 1 mm. (·04 in.). It is this fact which helps to make the winter cold more tolerable in these regions. In desert regions the absolute humidity is low alike in summer and winter.

A point of some interest, to which we shall have to return later in connection with mountain climates, is that the absolute humidity diminishes with elevation in a fashion analogous to the diminution of pressure.

Condensation.—The water vapour in the air condenses and takes liquid form so soon as the air is cooled to a sufficiently low temperature. As the cooling continues past the dew-point the minute particles of dust in the air serve as nuclei round which the vapour condenses, to appear as minute drops of rain, mist, etc. If the cooling takes place in the upper air, which is singularly pure of dust, then cooling may continue past the dew-point before condensation occurs. Such air is said to be supersaturated, and a further cooling, or contact with strata of air containing minute drops of water, may cause a rapid condensation of large quantities of water vapour—sudden, heavy showers of rain are probably produced in this way.

Air is ordinarily cooled below dew-point in one of the four following ways—

(1) The stratum of air which is in immediate contact with the surface cools directly at night by conduction of its heat to the cooling ground, and the layer immediately above cools by radiation. This gives rise to the layer of mist which one so commonly sees in summer lying in valley bottoms, or over sheets of water after sundown. It is, however, a phenomenon of limited importance, only obvious on calm, clear nights, and resulting only in the deposition of small quantities of water.

(2) Air which moves horizontally from a warm region to a colder one is cooled directly, and as a consequence may deposit its water vapour as rain or mist.

(3) The mingling of two masses of air of different temperatures may give rise to condensation. This necessarily occurs if both masses are saturated, because, as suggested on

p. 222, the capacity of air for holding water vapour is not a simple multiple of the temperature, air at high temperatures having proportionately a higher capacity for holding water vapour than air at lower temperatures. Further, if of the two masses that of higher temperature is near saturation-point, the mingling may induce such a lowering of temperature as to cause condensation. The amount of rain furnished in this way is, however, small.

(4) The most important cause of condensation is cooling due to expansion. When air is caught in an ascending current of air, as it rises it is subjected to diminishing atmospheric pressure. In consequence it expands, and with the expansion it cools, and the cooling may be enough to bring about condensation. It is obvious, therefore, that all cyclones, which are regions of ascending air currents, must be regions of precipitation.

Clouds.—The moisture condensed in these various ways may remain suspended in the atmosphere in the form of excessively fine droplets. Masses of such droplets form clouds, or, if viewed from close at hand, mist. Various names are given to the chief forms of clouds; it may be sufficient to note here that there are four main types: (1) Cirrus, formed of minute needles of ice, and having the appearance of white filaments; they occur very high in the air; (2) Cumulus, clouds occurring in great rounded masses, with one bright edge; though found at lower levels than cirrus clouds, they are still very high (2,000–6,000 metres, or 6,560–19,690 feet); (3) Stratus, clouds arranged in uniform layers; (4) Nimbus, low clouds, dark in colour, of vague shapes with torn edges; they form the characteristic rain-clouds.

Apart from the shape of clouds, another important point about them is the extent to which they cover the sky. The cloudiness is indicated by meteorologists by a scale which runs from 0–10, and indicates the amount of sky covered by cloud. Thus a cloudiness of 5 means that half the sky is covered with clouds. As a general rule the cloudiness reaches its daily maximum during the warmest part of the day and its minimum towards evening. The annual cloudiness varies greatly with the latitude, the topography, the position in reference to the sea, and so forth, showing a general correspondence to the rainfall. Over the surface of the globe we find that the cloudiness is greatest at the equator, where

evaporation is most rapid, reaches a minimum between lats. 15°–30°, then increases again to a maximum between 35°–50°, to diminish again towards the poles. These conditions are closely associated with the winds and rainfall, and show also great variation in detail on account of the distribution of land and water, etc.

RAIN.—If the minute droplets of water formed by condensation fall through layers of air warmer than that in which they were formed, and unsaturated, they may disappear. On the other hand, if several droplets fuse together and acquire a certain velocity of motion owing to the action of gravity, then the drops so formed fall to the ground as rain. The annual and seasonal amount of rain is exceedingly important, and it is easily measured by means of a rain-gauge, which consists of a vessel surmounted by a funnel, with an accompanying measuring glass. The amount of rain which has fallen is measured at fixed intervals, and recorded. Meteorological statistics usually give the amount for days or months, but an important point is also the period within which the fall took place, for a very heavy shower of short duration is, from the farmer's point of view, less valuable than a slow, steady downfall.

Rains may be regarded as of three different types, by no means of equal importance. The first, and on the whole the least important, are *Relief Rains*. When a current of air strikes against a mountain chain which lies athwart its course, the air is forced to rise. As it rises it cools (*cf.* p. 225), and tends to throw down its load of moisture. As the current passes on over the crest it descends the opposite slope. Now not only has it lost a considerable amount of its moisture, but as it descends it is warmed by compression. Thus a mountain chain which faces the prevailing winds will tend to have a heavy rainfall on the windward side, and a well-marked "rain-shadow" on the leeward side. The British Islands afford striking examples of such relief rains (see map which forms Fig. 86), but necessarily they produce merely local modifications of the rainfall.

The next type of rain is found in *Cyclonic rains*. These, again, are of limited distribution, for, as we have seen (p. 214), cyclones only occur over parts of the earth's surface; but where they occur they are important. The rainfall of the British Islands, for example, is largely cyclonic.

Of widest distribution is the third type, that of *Convec-*

Q 2

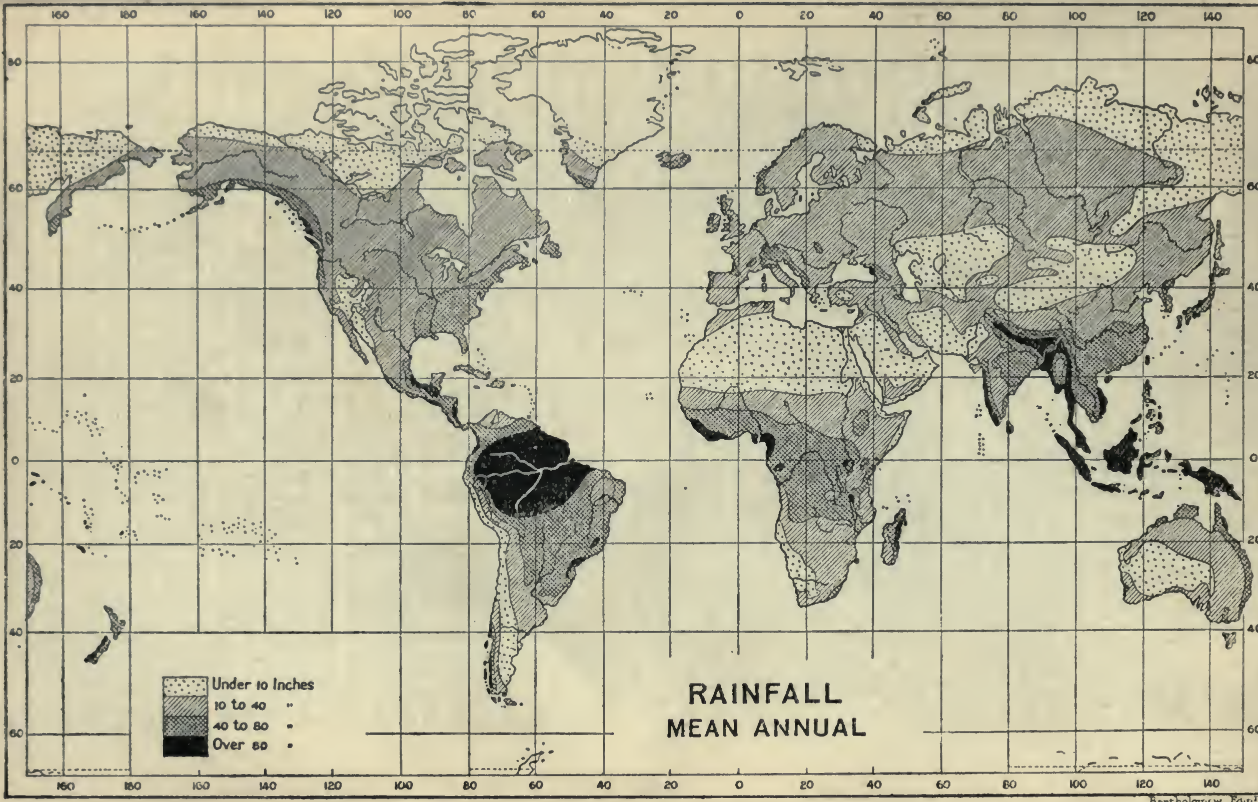


Fig. 77. Map showing the Mean Annual Rainfall of the Globe.

tional rains, due to rising currents of air. Round about the equator, as we have seen, lies a region of calms from which continual ascending currents arise; this is necessarily, therefore, a zone of heavy rainfall. We have also seen (see Fig. 75) that a second belt of calms occurs towards lat. 30° north and south of the equator, but here the air has a descending movement; it will become warmer as it descends, and this sub-tropical zone should form a region of drought, convectional rains being rare, and the district lying in a zone where the pressure is too high for many cyclones to occur. Beyond this zone northwards we come to the region where the westerly winds prevail, and as these blow over the surface of the sea they should become loaded with moisture. But they are continually travelling towards colder and colder regions, and there will thus come a time when most of their moisture has been lost, and, just as in ascending a mountain, even further cooling will not produce fresh rain. The net result is that the rainfall, apart from the disturbing influence of unequal distribution of land and water, effect of ocean currents, etc., should have the following distribution over the surface of the globe. Over the doldrums will be a region of heavy rainfall which will diminish steadily to a minimum over the horse latitudes, with their descending currents of air; beyond this there will be a second increase to a maximum in lat. 40°–50°, and then a steady diminution towards the poles. As we shall see, this simple theoretical scheme is much modified by local conditions. The monsoons, for instance, introduce great disturbances. When the monsoon of summer blows it carries moist air from the sea landwards, and there is a consequent heavy precipitation. In winter, the direction of the wind is from the cold, dry interior of the continents to the sea; such a wind will be dry, so that monsoon countries should tend to have a dry winter and a moist summer.

Distribution of Precipitation.—The map (Fig. 77) shows the main features as regards the distribution of mean annual rainfall over the surface of the globe. It will be noted that, as was to be expected, the maximum rainfall occurs round the equator, though even here the influence of relief is marked. Thus the mountains of central America carry the equatorial maximum far north, and similarly the lofty chains of the Himalayas and the adjacent ranges, combined with the influence of the monsoon, gives south-eastern Asia a very

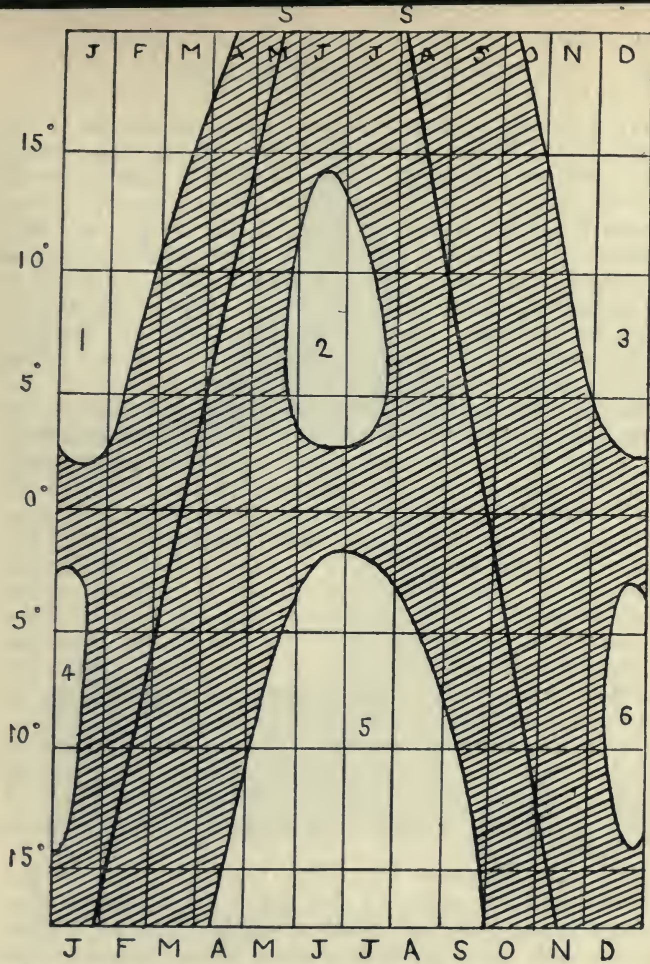


Fig. 78. Diagram to illustrate the seasons of precipitation in the intertropical zone. (After de Martonne.) (1) and (3) the long dry season north of the equator; (2) the short dry season; (4) and (6) the short dry season south of the equator; (5) the long dry season. The horizontal letters indicate the months of the year, the vertical figures the latitude north and south of 0°, the equator. The two lines marked S show when the sun is in the zenith at each meridian. The significance of the diagram may be appreciated in the following way. Take first a place a little to the north of the equator. There will be no entirely dry season here, because the sun is never very far away; but there will be a diminution in the fall in the period from November to January, for then the sun is far south of the equator, and a similar but slighter diminution in June, when he is far north of the equator (*cf.* Fig. 79 I, which shows the actual condition). Take next a place in latitude 15° N. or S. In summer there will be a maximum here, for the sun is always near and the heat thus great. In winter there will be a minimum, for then he is furthest away (*f.* Fig. 79, II).

heavy fall, the absolute maximum occurring on the slopes of the Khasi Hills, where Cherrapunji has a mean annual fall of 488 in., or 12,040 mm. Outside of this equatorial zone no large areas of heavy precipitation occur, though narrow bands are found, especially on the eastern shores of oceans. The regions of minimal precipitation occur in circumpolar regions, in tropical regions, and, generally, in the interior of continents, especially on plateaux surrounded by high mountains. As to the absolute minimum, Copiapo, on the west coast of South America, with an annual fall of ·3 of an inch (8 mm.), is the driest place known.

Seasons of Rainfall.—Of as great importance as the annual fall, however, is the season of fall, which influences the nature of the vegetation and the character of the crops to an enormous extent. The diagrams (Figs. 79, 81 and 82) illustrate the chief types, which may be briefly summed up—

(1) In the *equatorial* zone rain occurs throughout the year, with at the equator itself two maxima at the equinoxes, when the sun crosses the equator, and two minima at the solstices, when it is furthest away from the equator (Figs. 78 and 79 I). As the distance from the equator increases, the interval between the two maxima decreases, for the two periods of passage of the sun more nearly approach, and the equatorial zone thus passes into (2).

(2) In the *tropical* zone (Fig. 79, II) there is a rainy period coinciding with the passage of the sun overhead, and a dry season coinciding with the period when he is furthest away; thus the tropics are typically regions of summer rains and winter drought.

(3) In the *monsoon* type (Fig. 81), the rains are also typically summer rains, so that the monsoon regions may present themselves as merely a special type of tropical regions, but local conditions often induce modifications. Thus Madras (Fig. 81, 4) gets autumn rains, because the north-east monsoon reaches it after travelling over the Bay of Bengal, and it is, therefore, moist. In southern China (Fig. 81, 2) there is no dry season, though most of the rain comes with the monsoon of summer.

(4) In the *Mediterranean* region the rains come in winter; in early winter near the sea, *e. g.* at Lisbon (Fig. 82, IV), and in late winter further to the east, *e. g.* at Jerusalem (Fig. 82, III). Such a condition occurs not only round the Mediterranean Sea, but in all sub-tropical regions lying to

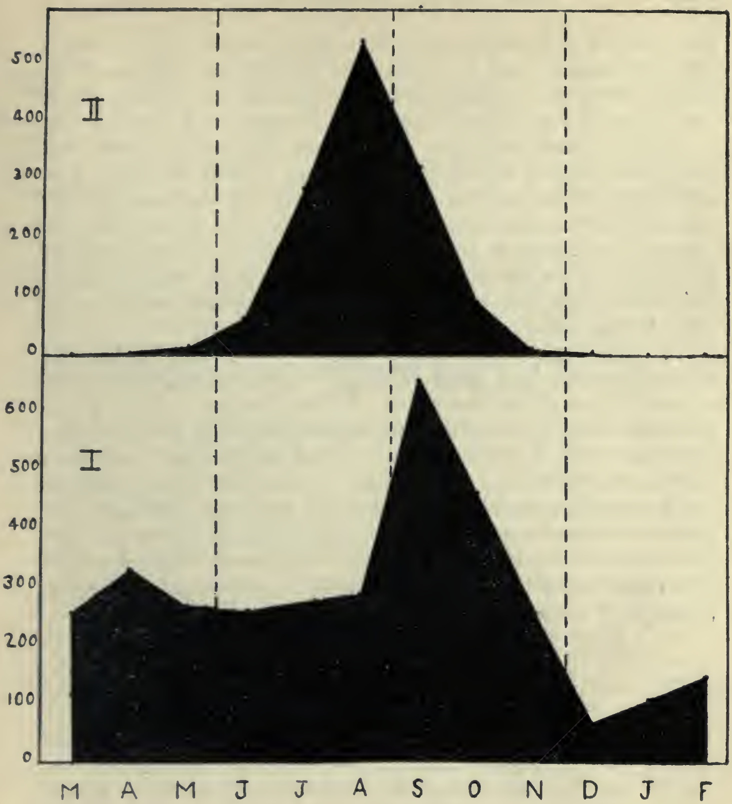


Fig. 79. Diagrams to illustrate tropical rainfall.

The vertical figures represent rainfall in cubic millimetres, the horizontal the months of the year beginning with March : thus the spaces demarcated by the dotted lines may be regarded as corresponding to the temperate seasons of spring, summer, autumn and winter. The lower figure (I) gives the precipitation for Kribi in the Karmerun (lat. 3° N.) and shows the equatorial type ; the figure may be regarded in the light of a section drawn across the diagram which forms Fig. 78, in lat. 3° N. The "long dry period" is suggested by the depression of the line in the months of December and January, the "short dry period" by the similar but less marked depression in May and June ; but it will be noted that there is no true dry season. There are two maxima, the greater being that of the autumnal equinox. II shows the precipitation at Bathurst (Gambia) in lat. 13° 24′ N. Here there is a marked summer maximum and a long dry season in spring and winter (*cf.* again Fig. 78).

the west of continents, which in summer lie in the zone of the dry trades, and in winter just enter the region of the moist westerlies; examples are California, the region round the Cape of Good Hope, Chili, south-western Australia, etc.

(5) In *higher latitudes* there is no dry season, the rain being distributed throughout the year. Near the sea, *e. g.* in western Europe (Fig. 82, VI), there is a tendency for the maximum to occur in autumn or winter; but this is not well marked, and there is sometimes both a summer and a winter maximum. As we travel eastward, however, and the rainfall diminishes, the summer maximum becomes well marked *e. g.* Prague (Fig. 82, V).

To sum up, both round the equator and in middle latitudes there is a good rainfall, more or less evenly distributed throughout the year. In the tropics there is a wet summer season and a dry winter season, but the monsoon regions, with a usually high total fall, show variations dependent upon local conditions. In the sub-tropical region, on the western margin of continents, we have mediterranean regions with winter rainfall, tending to be scanty as we pass from the sea inland. Other parts of the sub-tropical region are remarkable for their practically continuous drought, when they constitute desert regions.

CHAPTER XVI

THE CLIMATIC REGIONS AND THEIR CHARACTERISTIC PLANTS AND ANIMALS

Principles of Classification.—Hot, Temperate and Cold Climates.—Influence of Precipitation.—The Equatorial Type.—The Normal Tropical Type and Savanna Regions.—The Monsoon Tropical Climate.—The Chinese or Sub-tropical Type.—Mediterranean Climates.—Warm Deserts.—Maritime and Continental Temperate Climates: their Summer and Winter Temperatures.—Cold Deserts and Steppes.—The Norwegian and Siberian Types.—The Arctic or Tundra Climate.—Mountain Climates.

HAVING now considered the chief points in regard to general climatology and meteorology, we must proceed next to a general classification of climates. This is a matter of considerable difficulty, first, because, as we have already seen, numbers of minor causes introduce modifications which make a broad, sweeping classification impossible; and, in the second place, there are no hard and fast lines, one region passing gradually into another. The attempt to base a classification of climates upon purely meteorological data is thus one of much difficulty, and a considerable number of schemes have been suggested. In most cases, even when the scheme appears to be based entirely upon physical conditions, there is at least a tacit reference to biological phenomena, as these are affected by the conditions. In other words, a successful classification must always have a sufficiently close relation to human life to be of value to the geographer proper, as distinguished from climatologist or meteorologist, and it usually finds this relation in the effects of varying climatic conditions upon the growth of plants, man being almost everywhere dependent upon the plant world. We shall add, therefore, to our physical description of types of climate some notes upon the plants and animals of the different zones, to show how these respond to the varying conditions.

The two most important physical characters upon which a classification can be based are temperature and precipitation. Thus we speak of hot, temperate and cold climates. These types are distinguished both by the mean annual

temperature, and by the duration of the cold and hot periods when these occur.

Hot Climates are those in which the mean annual temperature does not fall below 20° C. (68° F.), and which, further, have no month whose mean temperature is less than this. While the diurnal variation may be great the variation from month to month is small, and does not exceed 5° C. or 9° F. This is sometimes expressed by saying that "night is the winter of the tropics."

Temperate Climates are those in which the mean annual temperature is less than 20° C., and which have some months (though always less than eight) in which the mean temperature falls considerably below this figure. The variation from month to month is well marked, so that there are seasons marked by temperature differences.

Cold Climates are those in which the majority of the months have a temperature of less than 5° C. (41° F.).

So far we have based our classification solely upon temperature, though, as we shall see, the groups named above are subdivided largely upon a basis of the amount and distribution of precipitation. But we have to recognise one major type based upon the paucity of precipitation—this is the Desert type, in which the mean annual precipitation is less than 25 cm. or 10 in. Finally, we have to distinguish Mountain Climates, which show certain special peculiarities.

With the exception of mountain climates, each of the four major types can be subdivided. Thus, in the hot type we have to distinguish between the equatorial climate, with heavy rainfall through the year, and tropical climates, with well-marked dry and rainy seasons. In defining a dry season we may note that a dry month in a hot climate is one with less than 5 cm. or 2 in. of rainfall, and in a temperate climate one with less than 2·5 cm. or 1 inch. Under tropical climates, again, we have to consider the normal type and the special conditions presented by monsoon regions.

Under temperate climates we have those without a definite cold season, constituting the sub-tropical climates, of which the Mediterranean is a well-marked variety, and, second, those with a cold season, *i. e.* four months with a mean temperature of 5° C. (41° F.), which again fall into oceanic and continental types. Again, the cold climates may be divided into those which have a mild season (*i. e.* four months with a temperature above 10° C. (50° F.), and those

with no mild season. Desert climates fall also into cold and hot types. Thus, our classification of climates may be arranged in tabular form as follows:—

Hot Climates.
- (1) Equatorial
- (2) Tropical, Normal type.
- (3) ,, Monsoon type.

Temperate Climates.
- Without cold season or sub-tropical.
  - (4) Normal or Chinese.
  - (5) Mediterranean.
- With cold season or cool temperate.
  - (6) Oceanic.
  - (7) Continental.

Cold Climates.
- With mild season.
  - (8) (*a*) Norwegian or Maritime.
  - (*b*) Siberian or Continental.
- Without mild season
  - (9) Arctic.

Desert Climates.
- (10) Warm desert.
- (11) Cold deserts and steppes.

(12) *Mountain Climates.*

These varied types we must now proceed to consider in detail. Their distribution is shown in Fig. 80.

(1) Equatorial.—We have already noted on p. 230 the general characters of the precipitation, and may give actual figures for rainfall and temperature for two typical stations to show the general characters of the climate.

Station.	Latitude.	Height above sea-level.	Mean annual temp.	July temp.	Jan. temp.	Rainfall in mm.
Jaluit (Marshall Islands)	5° 35′ N.	3 m.	27° C.	27·2°	26·8° C.	4,492
Manaos (Brazil)	3° 8′ S.	40 m.	26° C.	26·6°	25° C.	2,149

The first of the two stations named indicates what is called the oceanic type, which has a higher annual rainfall, a less

Fig. 80. Climatic regions of the world.
(1) Equatorial; (2) Tropical; (3) Tropical Monsoon; (4) Chinese; (5) Mediterranean; (6) Maritime temperate; (7) Continental temperate; (8a) Norwegian; (8b) Siberian; (9) Arctic and Mountain (all the minor mountain regions are omitted); (10) Warm desert; (11) Cold desert and steppe.

marked annual range of temperature, and a higher mean temperature than the continental type.

As to the distribution of this type of climate (Fig. 80) it is developed round the basin of the Amazon, and round that of the Congo, though it does not reach the east coast of Africa. It extends into Central America and embraces the lower half of the Malay peninsula, and the majority of the islands of the Malay Archipelago. In the oceanic form it also includes those islands of the Pacific which are included between lat. 15° N. and lat. 15° S.

The characteristic plant formation is the equatorial forest, well developed in the Congo and Amazon basins and in New Guinea, Borneo, and the other large islands of the East Indian archipelago. This forest is evergreen, and its distinguishing features are the enormous wealth of creepers and the density of the undergrowth. Creepers and lianes bind one tree to another, and quantities of epiphytes, *e.g.* orchids, cover the branches of the trees. In consequence, progress for man and large terrestrial mammals is rendered very difficult. A special feature of the equatorial forest, therefore, is the presence of purely arboreal mammals, some of which never descend voluntarily from the trees. Examples of equatorial arboreal mammals are the sloths, marmosets, and flat-nosed monkeys of Brazil; the lemurs, dog-faced monkeys and apes of West Africa and the East Indies; the tree kangaroos of New Guinea. Terrestrial mammals of large size are relatively uncommon in the equatorial forest, their movements, no less than those of man, being impeded alike by the dense forest and by the numerous broad streams, fed by the almost constant rainfall. On the other hand, reptiles of all kinds are abundant; the crocodiles of tropical waters generally and the great boas of South America are outstanding examples. Insects are also enormously abundant, especially many kinds of ants, also gorgeously-coloured butterflies, beetles, etc.

The equatorial forest is very unsuited to human activity, and in many parts of the globe lodges the most primitive types of humanity, the Papuans, for example, being in the Stone Age. The heat and humidity of the atmosphere makes exertion difficult, and the practical absence of seasons means that vegetative growth is continuous. In consequence, it is difficult for man to displace the luxuriant native vegetation in favour of his own crops, and the inhabitants of the forest as a rule cultivate but little.

Among the valuable products of the forest mention may be made of dye-woods, *e. g.* in Brazil; the oil-palm, *e. g.* in West Africa; sago, *e. g.* in Papua; and, from the standpoint of modern commerce, most important of all, rubber, *e. g.* in Brazil and the Congo region. The native inhabitants of the forest live chiefly upon its natural products, vegetable and animal, and, when they cultivate at all, usually confine themselves to the plants requiring the minimum of exertion, *e. g.* bananas, yams, cocoanuts, etc. In several separate parts of the globe, *e. g.* in the Congo region, in Papua, and in the Philippines, though the last lie just outside the area of equatorial climate, it is found that the inhabitants of the densest forest region are undersized as compared with the inhabitants of the more open regions, forming pigmy races. According to one view, these pigmies are an older race driven to the depths of the forest by the competition of higher forms, but, according to another, the undeveloped condition is a direct consequence of the unfavourable environment.

The higher types of cultivation are not widespread in equatorial regions. Coffee is produced just within the region or on its borders, as is also cocoa. In the East Indian islands spices are important, but on the whole the land is little cultivated.

Tropical Climates. (2) The Normal Type.—This type has a far wider extension than the equatorial, and can be subdivided into a great number of groups. We shall, however, only distinguish two varieties, which may be called the normal and the monsoon type. The first corresponds generally to the savanna type of vegetation, and we may take as an example Bathurst, whose rainfall we have already considered (see Fig. 79, II). The chief features of its climate may be seen from the following figures:—

Height above sea-level.	Latitude.	Mean ann. temp.	Hottest month.	Coldest month.	Rainfall in mm.
2 m.	13° 24′ N.	24·8° C.	26·4° C.	21·6° C.	1,333

These figures show that the chief contrasts with the equatorial type are the lower annual temperature, the increased range, and the smaller annual rainfall, which, as

we have seen, is so distributed throughout the year that a well-marked dry season occurs when the sun is furthest away. This type (Fig. 80) is found encircling the equatorial areas, especially in Africa and South America. In ocean regions the annual temperature range is diminished and the precipitation increased by the proximity of the sea, so that such regions are transitional to the previous type. Indeed, such areas as the West Indian islands are placed in the one group or the other by different authors. North and south the savanna belt passes into deserts, and in the island continent of Australia the great development of desert reduces the extension of the savanna region to a broad band in the north and north-west. India and south-eastern Asia generally we leave to be considered under monsoon climates.

From the biological point of view the special feature of the normal tropical climate is the fact that there is a dry season, varying in length with the latitude, during which the temperature remains high. Now, trees and shrubs, other things being equal, lose water (transpire) more continuously than herbaceous plants, because the latter die back to the ground in cold or drought, and spring up again when moisture and warmth return, while the former remain permanently exposed to drying winds. Thus, while in tropical regions the moist season, with its high temperature, is eminently favourable to all forms of plant life, the dry season acts more unfavourably upon shrubs and trees than upon grass and herbs generally. The tropical climate is, therefore, relatively unfavourable to forest growth, except where the proximity of permanent watercourses gives subterranean moisture, or the relief, the prevalent winds, proximity to the coast, etc., diminish the severity of the dry season. Thus, speaking broadly, the tropical climate corresponds to the savanna—that is, to regions of grass and herbs, with scattered trees of specially resistant types, and local development of forest where conditions are favourable. Except where special conditions intervene, the forest areas increase towards the equator, both in extent and density. They always diminish to the north and south as the desert regions are approached, and they are better developed towards the rainy sides of continents than towards the dry ones.

As to the characters of the individual trees, the leaf surface is often reduced, as is well seen in many acacias,

typical savanna plants; thorns and spines are frequent, a fact well illustrated in the euphorbias of Africa and the cactuses of tropical America; not infrequently the leaves are shed during the dry season, as in the mighty baobab of tropical Africa, this being a device to protect the tree against excessive loss of water; water-storing tissue is present in the aloes of Africa and the cactuses of America, and the huge trunk of the baobab is doubtless a similar adaptation. In Australia the eucalyptuses and acacias have arrangements for diminishing loss of water, and the curious casuarinas, which present a marked (though quite superficial) resemblance to gigantic horsetails, have their leaf surface reduced to a minimum. Generally, the typically tropical forest is as well characterised by the absence of luxuriance, as is the equatorial forest by its presence.

Of the herbaceous plants the grasses are important, and after the rains grow to a great height, affording shelter to many kinds of animals. There is, thus, great local luxuriance of pasture for grass-eating animals, and the fact that the onset of the dry season varies with latitude, makes it possible for such animals to prolong the period of abundance by migration. The savanna, therefore, and especially the African savanna, is the home of grass-eating mammals. Tropical Africa is especially characterised by its enormous wealth of large ungulates, notably antelopes, and it has, in addition, many peculiar animals, such as the giraffe. In the savannas of South America, where ungulates are few and the hollow-horned ones completely absent, large numbers of rodents occur, and Australia has marsupials, especially the grass-eating kangaroos.

From the human point of view the savanna has the great advantage that it does not, like the equatorial and parts of the temperate region, need to be cleared of dense forest. Its natural wealth of pasture suggests a utilisation of the soil for pastoral purposes, by the displacement of the native ungulates. This we find in tropical Africa, where such native tribes as the Masai and Kikuyu are pastoral peoples, the former practically not cultivating the land at all, and the latter very little.

Again, the marked seasonal variation in the rainfall in the tropical region favours the cultivation of the soil, for it imposes a periodical check upon the natural vegetation, and permits man to introduce his crops. The savannas of

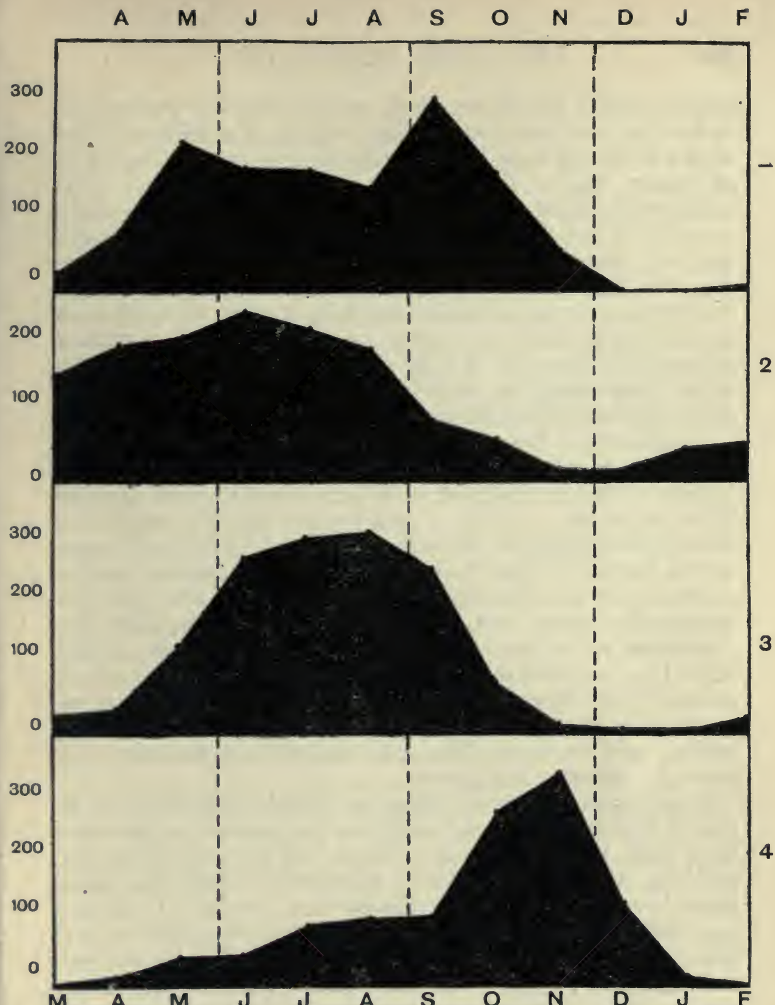


Fig. 81. Diagrams to illustrate Monsoon Rainfall.
(For explanation of letters and figures, see Fig. 79.)

Calcutta (3) shows the typical monsoon condition, heavy rains being limited to the period between May and September when the S.W. monsoon blows. At Madras (4), situated on the east coast, in the rain-shadow of the Ghats, it is the N.E. monsoon of autumn which brings most rain, the summer monsoon bringing smaller amounts. At Bangkok (1) the heaviest rain comes during the period when the S.W. monsoon blows, and during this period there are two maxima; but the N.E. monsoon also brings some rain (note the October precipitation). At Canton (2) there is no absolutely dry period, though most of the rain comes with the summer monsoon.

Africa, before the advent of the white man, were extensively —though not *in*tensively—cultivated by the natives. The crops obtained were for the most part those also found in monsoon regions (see below), but it is noticeable that, whether because of the poverty of the soil, which often consists of laterite (see p. 53), or because no tribe of African negroes used the plough, and few had any notion of manuring, the crops are small, and the land soon loses its fertility. In tropical America cultivation was carried on only on a small scale before the advent of the European, and in tropical Australia not at all. In all savanna regions cultivation is now being developed under European influence, the usual tropical crops being grown.

(3) Tropical Monsoon Climates.—All round the Indian Ocean, and extending to Further India, etc., we have a region under the influence of the monsoon tropical climate. A considerable number of sub-regions can be recognised here, but throughout the influence of the monsoons is seen in the increase in the total rainfall (except in certain special regions), in the drought of the dry season, even in sub-equatorial regions, and in the storms and atmospheric disturbances which herald the change of wind. As a general rule, the rain coincides with the highest temperatures, a point of great importance in connection with crops, but, as we have seen, in some cases the rain comes in the cooler season, and in Siam (Fig. 81, 1) both the summer and autumn monsoons bring rain.

The tropical monsoon region is densely peopled, and in many regions well cultivated, so that natural conditions have been much modified. Where the dry season is not too long, and the precipitation abundant, we find the monsoon forest, which in luxuriance and wealth of species approaches the equatorial type. Many useful species occur, such as innumerable palms, including valuable forms like the sago, the Palmyra, the betel-nut, etc.; camphor trees, and so forth. In the drier regions the luxuriant monsoon forest thins to savanna wood, and we have many adaptations to withstand drought. Thus the bamboos are characteristic, and are remarkable for their extraordinarily rapid growth when heat and moisture are both present; they are capable of withstanding long drought. Teak, which yields valuable timber, sheds its leaves in the dry season, and is thus able to resist the drought; many other similar adaptations occur.

The greater development of forest and of cultivation, as compared with tropical Africa, diminishes pasture areas, so that pastoral industries are not prominent. The forests lodge deer, oxen, rhinoceroses, elephants, etc., with the carnivores, *e. g.* tigers, which prey upon them. The denser regions have purely arboreal forms, *e. g.* apes, many monkeys, fruit bats, the flying lemur of the Philippines, many kinds of squirrel, etc. The upland regions, often densely forested, have a special fauna of their own.

Cultivation is carried on extensively. Rice is perhaps the typical cereal, though wheat is grown as a cool-season crop in parts of India, and millets are extensively cultivated. Rice is a crop of short duration, and is often grown as one of a series of crops taken off the same area in the course of the year. Owing to its deficiency in fat and flavour, various forms of oil-seeds are also grown, with many kinds of flavouring materials, and also pulses. Sugar-cane, a crop well suited for monsoon tropical regions, is much cultivated. Fibres, especially jute and cotton, are also suited to the climate, as are dye plants, such as indigo. Most of these crops have been grown for a prolonged period, while other plants have been introduced by Europeans, such as tea, cinchona, rubber, etc.; of these tea is really sub-tropical.

The SUB-TROPICAL CLIMATES occur in two well-marked types, of which that which we have called (4) NORMAL is sometimes called CHINESE, because it is well developed in China proper. In this case monsoon influences are still felt, but the temperature is lower than in the tropical monsoon region. Shanghai in China, and New Orleans in the United States, afford good examples, and we may give figures for both—

Station.	Lat. and Long.	Height.	Ann. temp.	Hottest month.	Coldest month.	Rainfall in mm.
Shanghai .	31° 12′ N., 119° 6′ E.	7 m.	15° C.	27° C.	2·7° C.	1,169
New Orleans	29° 56′ N., 92° 23′ W.	16 m.	20° C.	27·8° C.	12·7° C.	1,532

The great range of temperature as compared with tropical climates is very noticeable here. There is practically no dry season, the annual rainfall being high, but it is lower in autumn and winter than in spring and summer, the condition being thus comparable to those shown in the diagram

for Canton (Fig. 81, 2). In China the heavy rains are convectional and come in summer, but in winter cyclonic rains occur. Shanghai is, relatively, far to the north, hence its low winter temperature; it will be noted that New Orleans is much warmer in winter.

This type occurs not only in China, especially to the south, but also round the basins of the Parana and Paraguay in the Argentine, round Sydney and Brisbane in Australia, in the eastern side of South Africa, notably in Natal, and in the south-western United States. Where the conditions are favourable the region where this climate reigns is clothed in forest, which recalls the tropical monsoon forest in its luxuriance, and in its palms, tree ferns and bamboos. Examined more closely, however, it shows new features in the presence of conifers, especially species of pine and araucaria (monkey puzzle), and of evergreen oaks, laurels, etc. This temperate rain forest, as it is called, is of great interest in that in Tertiary times it was widely spread, and now lingers chiefly in isolated areas on the eastern sides of continents in subtropical regions.

The cultivated plants of this region are especially cotton, sugar-cane, tobacco, maize. In not a few parts of it such Mediterranean fruits as oranges, etc., have been introduced and thrive abundantly. Rice will also prosper in suitable situations, and in China the mulberry is extensively grown for silkworms; tea is also grown.

The animal inhabitants consist generally of a mingling of the cool temperate forms with tropical forms.

(5) Mediterranean.—If the Chinese type occurs in subtropical regions on the *eastern* side of continents, the Mediterranean one occurs in similar latitudes on the *western* side. As already indicated, its main peculiarity is the summer drought (*cf.* Fig. 82, III and IV); the winters are mild; the temperature range, and the mean annual temperature do not differ notably from that of the Chinese type. The type is best developed round the Mediterranean Sea. Here the vegetation is highly characteristic, and is the natural result of the physical conditions. The summers are warm, mean July temperatures of 27° C., as at Athens, and 25° C., as at Corfu, being not uncommon, and the total rainfall tends to be small except on the sea margins (annual precipitation at Athens 402 mm., at Jerusalem (Fig. 82, III) 647 mm.). In consequence, the plants are exposed to great

loss of water. The drought of summer excludes grass, except where local conditions, *e. g.* relief, produce summer showers, for the surface layers of ground dry out completely in summer. Herbaceous plants, therefore, must run through their activities in the early part of the year before the

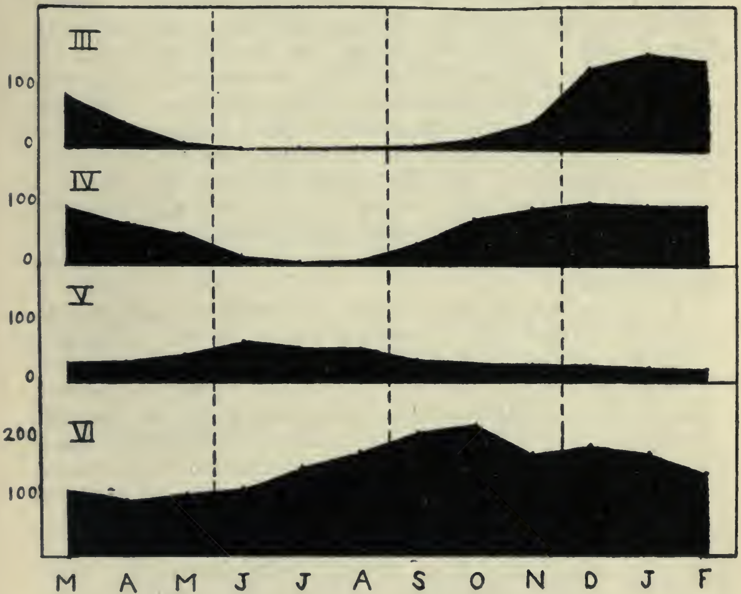


Fig. 82. Temperate and sub-tropical rainfall. (For explanation see Fig. 79.)

III and IV are respectively Jerusalem and Lisbon, and therefore both illustrate the Mediterranean type with winter rains and summer drought. Note the earlier onset of the rains at Lisbon in autumn and the consequent diminished length of the dry period as compared with Jerusalem. V, Prague, illustrating the warm temperate "continental" type, with no absolute drought, but a summer maximum mostly due to convectional rain of the thunderstorm type. Note the occurrence of the maximum in early summer when the temperature is changing rapidly. VI, Bergen, the oceanic or maritime type, with an autumn and winter maximum, owing to the winter cyclones.

drought commences. Hence the glory of bulbous and tuberous-rooted plants in the spring. Certain trees and shrubs are better able to withstand drought, for their roots

can penetrate to the deeper layers of the soil, which retain the moisture, but they must have arrangements for diminishing loss of water, *e. g.* small, silvery leaves, development of thorns and spines, etc. In the lower grounds the typical formation is now the maquis, or shrub thicket, consisting of small trees or shrubs, all protected against drought; among the species are wild olive, arbutus, myrtle, many species of cistus, etc. Where conditions are favourable, evergreen forest occurs, especially of conifers, live oak, cork oak, etc., while on the hill-slopes species like sweet chestnut and even beech, both deciduous trees, occur. Such forests were probably once widely spread, for the region has suffered much from deforestation. On the whole, however, the region is poor in *species* of trees, many of these now grown having been introduced. As compared with the savanna forest, the trees here suffer less from drought, owing to the lower temperature.

As in the case of that region, the native animals include types both from the temperate region to the north and from the tropics to the south. In regard to domesticated animals it is noticeable that the general scarcity of pasture makes the pastoral industries unimportant, but the uplands feed goats and sheep, and the forests of nut-bearing trees, *e. g.* oaks, make the pig an important animal. The cultivated plants are interesting. Even where the temperature is high the summer drought excludes such plants as sugar-cane, rice and cotton, which demand much moisture in the growing season, and these are only cultivated where irrigation is possible. Maize, also, is generally excluded for the same reason, though it grows in the damper parts. On the other hand, wheat, sown in autumn, grows well and ripens in the early summer, before the intense drought begins. It was preceded in historical time by barley, which is still grown, especially where conditions are at all unfavourable. In the monsoon regions, as we have seen, and indeed in the tropics generally, cereal crops often only form one of a series of crops taken off the same ground during the year, the other crops being also short-lived annuals. In the Mediterranean area the drought makes it impossible to grow herbaceous plants in the hot season except with irrigation, and thus the hottest part of the year would remain unutilised were it not for the abundant fruit-trees, whose culture occupies the agriculturist throughout all the warmer

season. The typical fruit-bearing plants are olive and vine, but we have also all the citrus group—oranges, lemons, citrons, etc.; many nuts, such as almond, pistachio, etc.; pomegranates; peaches, and so forth. Many of these plants will grow outside the Mediterranean area, and are so cultivated, but it was within the region that their cultivation was first fully developed, even in the case of introduced plants like oranges, and the development of the art here must be regarded as a result of the climatic conditions, for it affords a means of utilising a season which would otherwise be useless. The mulberry, another tree which is cultivated, was introduced from China, and permits of a wide, though not very extensive, rearing of silkworms. The industry is hampered by the climate, for the drought does not permit the tree here, as in monsoon regions, to yield several crops of leaves for the use of the caterpillars.

(10) We may now turn to the Warm Desert climates, which tend to separate the tropical from the sub-tropical climates. As we have indicated, the tropics show increasing drought as we pass north and south, and in both hemispheres we therefore come upon a more or less interrupted band of deserts, separating the tropical from the sub-tropical zone. Here the total rainfall is less than 10 inches (25 cm.), and the time of fall is uncertain; the annual range of temperature is also great. Of such deserts, the best-known example is the Sahara, but we find the same type in the interior of Australia, in southern Africa, in South America, and in the west of the United States. Such deserts occur on the western sides of continents, and form a belt separating the Mediterranean climatic region from the tropical one. The greater extension of the Chinese type of climate on the eastern side of continents prevents their development there. Such regions are often absolutely useless—as in the case of the Australian desert, often said to consist of spinifex and sand. Elsewhere there are intervening regions of fairly rich pasturage in the waste, permitting of a limited pastoral industry, the horse and camel being especially reared. Where water can be supplied for irrigation good crops may be obtained, and many of the Mediterranean plants will grow. In the Sahara and neighbouring regions the typical plant is the date-palm, which is tolerant of very dry air if water can be supplied to the roots. The natural plants of the desert show in an exaggerated form the features we have

Fig. 83. Isothermal Map of the British Isles for January. (After Buchan.)
Note the direction of the Isotherms.

noted in those of the tropical savanna and of the Mediterranean region. They bear thorns and spines, many devices for storing water occur, leaf surfaces are reduced, and so on. The animals are usually swift footed, so that they can pass rapidly from one oasis to another; they are often of a uniform sandy colour, *e. g.* camel, or they may, like the camel, have special adaptations enabling them to go for long periods without water.

We have just seen that in the sub-tropical region there is a marked difference between the eastern or Chinese type and the western or Mediterranean type. The same thing happens in the next zone, the temperate, with cold season, giving us the familiar distinction between (6) MARITIME or oceanic and (7) CONTINENTAL, cool temperate climates. But it should be emphasised that it is not only the distance from the sea which produces the difference between the two types, for an eastern seaboard, *e. g.* that of temperate North America is "continental." The "maritime" effect found on the western coasts of continents in temperate latitudes is due to the prevailing westerly breezes, and to the fact that these in winter blow from relatively warm seas, and in summer from relatively cool ones. Like the Mediterranean climate, the temperate maritime one has a limited distribution, and, as in its case, this extension is greater in Europe than elsewhere. In Europe the area covered by this belt comprises the densely populated British Islands and a strip along the coast of the continent from Galicia to Hamburg. Elsewhere it forms a narrow belt in British Columbia, covers a portion of southern Chili, and appears also in south-east Australia, Tasmania and New Zealand.

The continental type has a far wider extension. It covers the greater part of Europe, and has a limited extension into eastern Asia, which on account of the elevation and drought has mostly climates of other types. To the far east it reappears in Manchuria and Japan. In the eastern United States it has a wide extension, and reappears in eastern South America in the region south of the La Plata, whence it extends inland to the north-west.

As a type of the "maritime" variety, we may take England. The maps (Figs. 83 and 84) show the isotherms for January and July. We note that in the latter month the isotherms have, roughly speaking, an east to west course, the course we should expect. The warmest region is that round

Fig. 84. Isothermal Map of the British Isles for July as compared with those in Fig. 83. (After Buchan.) Note the direction of the Isotherms.

London, with a temperature of 64° F. (17·8° C.), the coldest lies near the Cheviots, the nearest isotherm being 15° C. (59° F.). In January the conditions are very different. The highest isotherm is 6·7° C. (44° F.), and runs from Cornwall north-westward to the south-west of Ireland. The lowest isotherm runs from the mouth of the Thames in a north-westerly direction, curving round to meet the coast at Flamborough Head, and is that of 3·3° C. (38° F.). Over much of England the winter isotherms have generally a north to

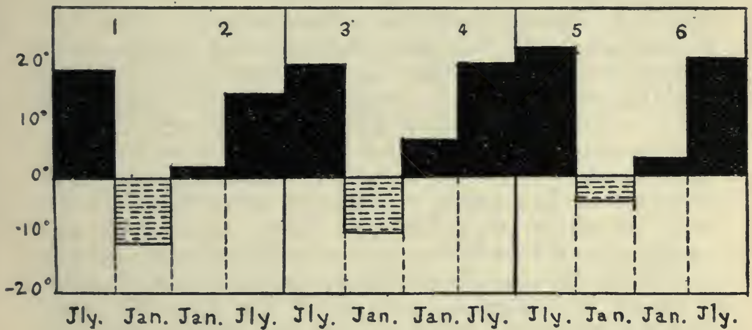


Fig. 85. Diagram to illustrate the temperature ranges in the "continental" and "maritime" types of cool temperate climate.

The diagram shows the mean January and mean July temperatures in three pairs of stations, each pair including places in the same latitude but not the same longitude. Temperatures below 0° C. are shown by shading, those above are in black.

1. Moscow, lat. 55° 46′, long. 37° 40′. Height above sea-level 160 metres.
2. Edinburgh, lat. 55° 66′, long. 3° 11′ W. Height 82 metres.

3. Kursk, lat. 51° 45′, long. 36° 8′ E. Height 210 metres.
4. Valentia, lat. 51° 54′, long. 10° 19′ W. Height 25 metres.

5. Odessa, lat. 46° 29′, long. 30° 44′ E. Height 70 metres.
6. Rochelle, lat. 46° 9′, long. 1° 10′ W. Height 23 metres.

It will be noted that in each pair the left-hand station has the continental type of climate; the right-hand one the maritime one. The differences in the January temperatures are especially striking. Kursk has a somewhat low July temperature for its position, but its elevation above sea-level should be noted in this connection, and its position on a pleateau.

south direction, so that places to the west are warmer than those to the east irrespective of latitude. Rainfall also diminishes in passing eastward (Fig. 86). The cause of the

temperature conditions is the fact that the west winds strike the western seaboard warm from the ocean, and liberate also much latent heat as they throw down their moisture. As the air ascends over the mountain backbone it loses much of its water vapour, and descends the opposite side as a drier wind. The eastern side also is exposed to the chilly east winds from the snow-covered continent.

This apparent independence of cold and latitude in winter is not confined to the British area, but occurs in western Europe generally, throughout which the north-south direction of the January isotherms is characteristic. Thus, if in January we draw a line from Brest eastward along a line of latitude, we shall find that whereas at the coast it crosses the isotherm of 7° C., in Hungary it cuts the isotherm of −3° C., a difference of 10° C. without any change in latitude. On the other hand, in summer the extremes are 18° C. to the west and 21° C. to the east, the difference now being in favour of the eastern region. In other words, to the west the winters are milder and the summers cooler, the springs slow and backward; to the east the winters are very severe, but the summers are hotter, and the change of season in spring is necessarily more rapid (see Fig. 85). The rainfall conditions in the two types are shown in Fig. 82, V and VI.

The natural vegetation throughout the temperate region consists, or once consisted, largely of temperate deciduous forest, replaced on mountains and to the north by the coniferous forest. As the rainfall diminishes with distance from the sea, the temperate forest passes into steppe, with a seasonal abundance of pasture. But the temperate forest has been very largely destroyed in Europe, and is being seriously attacked in North America, and, unlike the tropical forest, it was never dense enough to prohibit the free growth of pasture among the trees. With the destruction of the forest, pastures have been enormously increased, and, as contrasted alike with the Mediterranean and monsoon regions, the cool temperate is one of very abundant pasturage, increasing to the west with increased rainfall. The pastoral industries have thus always been important.

Of the crops under cultivation the typical cereals are the hardier ones, barley, rye, oats, etc., but in special circumstances, especially where there is a locally reduced summer rainfall, wheat flourishes superbly, giving, *e.g.* in the wheat

belt of England, very high yields. As the total rainfall diminishes to the east in Europe, and to the west from the Atlantic seaboard of the United States or the Argentine, we find in all three regions an inland wheat belt, the growth of the plant being assisted by the great soil fertility—black lands of Russia, virgin soils of United States, etc. In addition to cereals, all sorts of crops which do not demand great heat are grown, sugar beet being one of great interest and importance, to which the continental variety of the cool temperate climate is well suited. The summer rains make the warmer parts well suited also to maize. The potato, an introduction from a region of mountain climate, has an importance in the cooler and damper parts, *e. g.* in parts of the British Islands and in North Germany, which it does not possess in the warmer and drier regions.

The large indigenous mammals have been exterminated or reduced in numbers throughout the zone, owing to the value of the land for cultivation or pasturage. We may note that the original wealth of pasturage in the forest glades accounted for the presence of a number of large ungulates, such as the aurochs, many kinds of deer, wild boar, wild sheep and goats on the hills, etc. Carnivores were also numerous, including wolf, bear, badger, wild cat, and many small forms, as weasel, stoat, marten, etc. In addition to not a few rodents of forest type, as squirrel and dormouse, the region has always been liable to incursions of steppe forms, of which the hamster and rats have kept their hold.

(11) Cold Deserts and Steppes.—As the sub-tropical Mediterranean region dies away to the east and the south into the warm desert region, so the continental temperate climatic region dies away eastward into the cool desert. Especially in the case of basins of inland drainage (p. 47), we find the rainfall diminishes so much that plant life becomes stunted and desert conditions supervene. On the other hand, the relief or the distribution of pressure may result in an increased rainfall, sometimes constant, sometimes limited to certain seasons, or occurring only in certain years. Then the desert is replaced by steppe. This climate, oscillating between steppe and cool or cold desert, is widely spread in Asia, especially round the Aralo-Caspian depression, and reappears in the western United States. In a slightly modified form, with increased rainfall, it appears in Patagonia. These steppe and desert regions are of

extraordinary interest, because their human and animal inhabitants alike have always tended to overrun neighbouring regions. Forests are necessarily absent, though trees may be represented, *e. g.* by tamarisks or acacias. Grass is locally abundant, as are herbaceous plants in general. Like the tropical savanna of Africa, therefore, the region is very rich in grass-eating mammals. Among these are wild horses, camels, antelopes, *e. g.* the saiga and the gazelle, sheep and goats on the uplands, rodents, such as marmots and jerboas, etc. The region is thus naturally adapted to pastoral industries, and there are alternating periods of scarcity and abundance, the latter apparently determining a vast increase in individuals, which in the subsequent period of scarcity brings about encroachment on neighbouring lands. Where irrigation can be employed the land becomes exceedingly fertile, *cf.* the ancient civilisation of Mesopotamia, and the prosperity of the Mormons in Utah.

COLD CLIMATES.—We come next to the cold climates, where we may distinguish those (8) where at least four months have a temperature above 10° C. (Norwegian and Siberian type) from those (9) in which there is practically no warm period of any importance, this forming the Arctic type. The *Norwegian type* (8*a*) corresponds to the "maritime" type. It occurs in north-west Europe, in Alaska and in the extreme south of South America, and is mild and rainy (see Fig. 82, VI), with a very cold spring. The natural vegetation consists typically of coniferous forest, and the animals are of northern type. The hardier temperate crops, rye, oats, potatoes, will thrive there, and pastoral industries can be carried on to a limited extent, especially the rearing of sheep—or, further north, of the reindeer. Lumbering is important in the forests.

The *Siberian type* (8*b*), equally developed in Siberia and in the north of North America, is much drier, and in Siberia becomes excessively dry and extreme. Where the temperature and rainfall permit, *e. g.* in eastern Canada, coniferous forests grow freely, as they do also throughout much of Siberia. These forests give rise to lumbering industries and also to the fur trade, the forest animals (ermine, beaver, bear, marten, etc.) yielding valuable furs. In many regions short-lived temperate crops can also be grown, and the cultivation of wheat is being pushed to its extreme northern limit in both hemispheres.

(9) Arctic.—As the temperature steadily diminishes with the approach to the pole the dryness and cold stops all arborescent vegetation, and we reach the tundra region, widely spread round the north pole. Here the sub-soil is permanently frozen, and the short mild season permits only of the growth of herbaceous plants and the flowering and fruiting of low, berry-bearing shrubs. During a short period, however, the region offers rich pasturage for herbivorous animals, at least in the more favoured localities. Here, therefore, we find reindeer, musk-ox, polar hare, lemming, etc., with such carnivores as polar bear and Arctic fox. Most of the animal inhabitants are migratory, and the land yields but little to man, though the wealth of the sea permits a marginal population of Eskimo, etc.

(12) Mountain Climate.—We have finally to consider this type, which shows many peculiar features. In any climate altitude brings a lowering of temperature, a rough general calculation being ·5° C. for every 100 metres of elevation. Again, the range of temperature is diminished, the mountain climate thus approaching the maritime type. There is, however, a very marked difference between slopes exposed to the sun and those sheltered from its rays. On the sunny side crops will grow at a much higher elevation than on the shady side, and in the Alps it is often noticeable that the houses and fields occupy the one side of the valley, while the other and colder side retains its forest covering. Similarly, on a mountain slope there is often a difference as to precipitation between the two sides; that which faces the rain-bearing winds is much wetter than the other. Up to a certain height the precipitation increases with the height, beyond that it steadily diminishes. It will be recollected that in latitude a similar condition occurs, the precipitation diminishing towards the poles, after a maximum in temperate latitudes. On the mountain, just as in latitude, the zone of maximum fall is marked by forest growth, and just as the tundra appears in the dry polar zone, so towards the mountain tops we have an alpine zone, with no trees, but low bushes and many flowering plants. As in the Arctic zone this upper region furnishes good pasture, and the mountains are typical pastoral areas, *cf.* the Alps, Tibet, etc.

We have stated above that temperature diminishes with altitude on mountains, but to this statement a note must be added. In calm weather in winter, cold air shows a marked

tendency to sink to the bottom of valleys, and therefore the temperature here is often considerably lower than some distance up the slope. This fact is well known to mountain folk, and in the Alps it is notable that the villages avoid the bottoms of the valleys, and occur sufficiently far up the mountains to avoid the effects of these "inversions of temperature."

One other point about mountain climates must be noted, and that is the occurrence in mountain regions of violent winds, blowing down the slopes of the mountains, and bringing with them air which is at once warm and dry. Such a wind in the Alps is called the foehn, and the term is now applied generally, though the wind has often special names in the districts in which it occurs. For example, the chinook wind of the Rocky Mountains is a foehn wind. In Europe the foehn blows in the Alps when the pressure is low in the north-west of the region and high in the Mediterranean area. In consequence of the distribution of pressure the moist air rises up the southern slope of the Alps, depositing its moisture as it rises; as it tops the crest it flows down the opposite slope with great and increasing velocity, being meanwhile warmed and dried by compression. Thus a period of foehn wind means dry and warm weather on the Swiss side, with clouds and rain on the Italian side, and great difference of temperature on the two sides of the chain. Foehn winds are only known in temperate latitudes. When the region of origin is cold compared with the region which the wind reaches ultimately, it appears as a cold wind even after warming by compression; the *mistral* of the Rhone valley and the *bora* of the Adriatic are such winds.

As to the distribution of mountain climate, we may note that in its extreme form it is especially well developed in Tibet, with its high mean elevation, and it has also a considerable extension in the Rocky Mountains. In the hotter parts of the world, *e. g.* in South America and tropical Africa, the mountains hardly do more than induce local modifications of climate, bringing, for example, sub-tropical or temperate islets into the middle of tropical regions. Elsewhere, *e. g.* in the Alps, Pyrenees, etc., the extent of ground affected is not great, though the biological and social changes induced are of much interest.

CHAPTER XVII

WEATHER CHARTS AND BRITISH WEATHER

Weather in the Equatorial Zone and in Monsoon Regions.—Contrast with Conditions in the British Islands.—Cyclones.—Anticyclones.—Construction of Weather Charts.—Weather under Cyclonic Conditions.—High-Pressure Conditions.

Weather in the Equatorial Zone.—As we have seen, while under climate fall to be considered the mean meteorological conditions of a particular locality, the weather of the locality is the sum total of the conditions at a given period. Now in some parts of the globe the weather conditions are remarkably uniform, so that safe deductions as to climate can be drawn from observations made over a very limited period. On the other hand, in other regions the variation is so great that long periods of observation are necessary before conclusions can be drawn, and even after this has been done we can have little certainty in regard to the probable conditions which will prevail at any particular time. Of the first type the equatorial zone is a good example. Here from day to day, and, speaking broadly, from season to season, the conditions are similar. The temperature falls to a minimum before the dawn, and the early part of the day is damp and misty. As the temperature rises steadily to its markedly uniform maximum, the mists clear and evaporation goes on rapidly. In consequence heavy clouds form, and in the afternoon there are heavy showers of rain, often accompanied by a thunderstorm. Thereafter the temperature falls rapidly, and so the cycle recommences. This sequence of events can be foretold with reasonable accuracy throughout the year, and the variants upon it are small, though, as we have seen, there is a seasonal difference in the amount of rain which falls.

Weather in Monsoon Regions.—Turn next to India as a type of a monsoon region. Here there is considerable uniformity during periods of many weeks, but well-marked seasons occur, separated by changeable periods. The

annual sequence is something like the following: From October to January we have the cool season, the temperature being 60°–70 F. (16°–21° C.) in the Indo-Gangetic plain, and increasing rapidly to the south. During this period the rainfall is irregularly distributed where it occurs, and the winds are light, the prevailing direction being north-easterly. With February the temperature begins to rise, and from March to May the weather is exceedingly hot and dry. During this period the wind begins to swing from north-east through east to south-west. In June the "bursting" of the monsoon takes place, that is the south-west wind begins to be accompanied by heavy rain. The change often takes place with great suddenness, and cyclonic disturbances may occur. Its date is uncertain, a late monsoon being generally a weak monsoon, with insufficient rain. The heavy rains last, with breaks, till September or October, when the cycle recommences. Within the periods indicated there is very considerable constancy, and forecasting in India, apart from storm predictions, is chiefly concerned with the attempt to predict the date of the "bursting" of the monsoon, and the probable intensity of the rainfall. As the complete reversal of the winds depends, as we have seen, upon the differential heating of the land in the interior of Asia, anything which checks this will retard the onset of the south-west wind, and probably diminish its force. Thus an unusually heavy snowfall on the mountains seems to retard the onset of the rainy season and to be associated with less precipitation than usual, for part of the sun's heat has to be used up to melt the snow, before the temperature of the ground can be raised. The point to be emphasised, however, is that a traveller arriving at India in any particular month can form a very fair idea of the probable weather he will experience.

Weather in the British Islands.—It is quite otherwise with north-west Europe, and especially with the British Islands. A traveller arriving in January at any English port may find the ground covered with snow, the sky blue and clear, the temperature low, but he is just as likely to find the air mild and foggy, or a strong wind raging. Within limits a doubt occurs at all periods of the year, for our weather is uncertain at all seasons; at no time are we safe from storms and heavy rainfall, and at every season the temperature is markedly variable. Now weather

Fig. 86. The Average Annual Rainfall of the British Isles. (After H. R. Mill.)

variations affect, to an important degree, a great many sections of the community. To a seafaring nation every storm represents loss of life and property, and we are notably a seafaring nation. To miners great variations in pressure are of much importance, for mine explosions occur in close relation to such variations, and Great Britain is a country of mines. Again, especially at certain seasons, sudden temperature variations, or heavy, or deficient, rainfall, or high winds, have important effects on agricultural crops. In all cases some of the bad effects of marked changes of weather can be guarded against if the persons concerned have adequate notice. In consequence we find that weather forecasting, even to the limited extent to which it is meantime possible, is of great public importance in temperate regions, especially in such regions as the British Islands.

Let us note first the special reasons which render the region one of such variable weather. We have already studied the pressure distributions over the lands and oceans in summer and winter, and know that over the Atlantic Ocean the variation is relatively small, while over the huge continent of Eurasia the winter high-pressure area is replaced by a low-pressure area in summer. The British Islands, with the portion of the continental seaboard which shares their climatic characters, lie thus at a junction zone, a region necessarily of constantly varying meteorological conditions. Further, our area lies in the permanent low-pressure belt which corresponds to the prevailing westerlies, the persistence of this low-pressure belt being due to the fact that in these latitudes cyclonic systems are continually travelling westward. In the southern hemisphere, where the conditions are remarkably uniform, the belt of westerly winds—the "roaring forties"—seems to be marked by a nearly constant band of cyclonic eddies, following each other eastwards with great speed. In the northern hemisphere the conditions are different, owing to the land masses which interrupt the uniformity of the pressure conditions. To realise the nature of these differences we must note some of the characters of cyclones in a little more detail.

Cyclones.—All cyclones are remarkable for their large diameter and small vertical height. Thus an average-sized cyclone may be three or four hundred miles across, but only some 5–7 miles in height. A weak cyclone is one in which

the barometric gradient (p. 212) is slight, a strong or deep one shows a well-marked gradient. In the former the circulation of the air is uncertain and feeble, in the latter it may reach the force of a gale. Such strong primary cyclones originate over the sea. In the case of those affecting our climate, a point off the coast of Newfoundland, near the meeting of the Gulf Stream and Labrador current, is a common place of origin. Such a vortex travels across the ocean at a speed which may be as great as thirty miles an hour. Let us suppose that it now impinges on a land surface, *e. g.* on the relatively high mountains which fringe the western coast of Great Britain. To surmount the obstacle the air must rise, and this rising, as we have seen, is accompanied by condensation, which liberates heat. The liberation of the heat strengthens the upward current which maintains the cyclone, and thus accentuates the cyclonic condition. But while when the cyclone is moving over the sea the winds which enter it are necessarily moisture-carrying winds, yielding fresh supplies of moisture to feed the cyclone, as it travels landwards such moisture-carrying winds are no longer obtainable. Again, in winter as the cyclonic areas approach the continent they come more and more into the influence of a region where the temperature is low and the pressure high, *i. e.* into an anticyclonic region. These two causes combined, the fact that the ascending current of the cyclone is slackened by lack of moisture in the incoming winds, and that the moving vortex is approaching an anticyclonic area, not only weakens it but also causes it to avoid the continental area. As meteorologists say the anticyclonic area over the continent "fends off" the approaching cyclones. The total result is that the cyclones which approach the British Islands from the west tend to travel away to the north-east, where they die away in the region of Scandinavia. Sometimes they travel up the English Channel, sometimes along the oceanic border of the Islands, sometimes across the north of Scotland, sometimes across England, and so forth. The point is that while it is excessively difficult to form in advance an accurate idea of the probable course of any particular cyclone, yet meteorologists can make certain general statements as to the probable number of cyclones which in, say, a year will follow the various possible tracks.

The next point is to consider the difference between

summer and winter conditions as regards cyclones. In winter, as we have seen, there is very high pressure over the Eurasian continent, *i. e.* a condition of descending currents over that region generally. These descending currents must be balanced by ascending currents in some other region, and the result is the generation of many primary cyclones over the North Atlantic. These cyclones produce the stormy winds and rain of autumn and winter, and result in the tendency to a winter maximum of rainfall in the Norwegian type of climate (*cf.* rainfall of Bergen in Fig. 82, VI). But as at this time the protecting action of the continental anticyclone is strongest, this cyclonic rainfall will have a very limited extension into the interior of the continent. It extends furthest where the mountain barrier of the British Islands, etc., is lowest, and disappears soonest where it is highest. Thus the wheat belt of eastern England, protected by the Welsh mountains, has almost a "continental" type of climate.

In summer the absence of the continental anticyclone permits the cyclones to penetrate further into the continent, but then the mechanism producing them is weakened, and they are mostly shallow, and lead to the production of secondary low-pressure areas, giving rise to thunderstorms and local heavy rains. It is to these local disturbances that the "continental" type of climate owes its tendency to a summer maximum of rain (*cf.* Fig. 82, V).

Anticyclonic Conditions.—When the British Islands are not under cyclonic influences they fall into one of the great anticyclonic areas which surround them, and change with the seasons. Thus our area may lie in an extension of the Atlantic permanent high-pressure area, or in the continental winter high-pressure area; again, since beyond the low-pressure belt of temperate latitudes there is another high-pressure belt to the north of us, we may temporarily come under the influence of this area. The extension of the Atlantic, the winter continental, or the far northern high-pressure belt over our area means usually settled and calm weather, the temperature varying greatly with the season when the extension occurs; the approach of eastward-moving cyclonic systems disturbs this equilibrium, bringing wind, rain and temperature changes. Obviously, then, weather forecasting in our area means chiefly the attempt to predict the approach of cyclonic systems. As yet the conditions which determine the origin of cyclones in the Atlantic are not known, or are

only surmised in the most general fashion. But as cyclones approach with only a moderate velocity, and our islands project far into the ocean, they can be recognised early and their probable course can be predicted with fair accuracy. As it is clear that the sooner they are recognised the longer warning can be given, stations in the ocean are obviously of first importance. To some extent these are now supplied by ocean-going ships furnished with wireless telegraphic instruments, which can communicate information of approaching storms long before these reach the coastal stations. Further, telegraphic communication with Iceland—a true outpost in the ocean—has greatly improved the power of accurate forecasting, but even so it can be done only for relatively short periods in advance.

Weather Charts.—Weather forecasting at the present time is based upon what are known as weather charts, which in the British Islands are regularly constructed and published by the Meteorological Office. Their construction involves first the reception of a great number of observations transmitted from separate stations. The observations include readings of the barometer and thermometer, a statement of the direction of the wind and an estimate of its force, and a note upon the condition of the sky and "weather" in the narrow sense, *i. e.* whether it is raining or not, whether the sky is clear, and so forth. These observations are then plotted on a chart, various conventional signs being used in order that as much information as possible may be represented. In the plotting the readings, *e. g.* of the barometer, at the different stations are first entered, and then isobars are drawn at intervals of tenths of an inch. Now it may quite well be that the readings at the different stations do not differ from each other by exact tenths of an inch, so that the lines must be drawn by interpolation, the underlying principle being that the variations in pressure will take place uniformly between the two stations nearest to the line to be drawn. Thus the map as published does not only represent facts; it is the result of an interpretation of the facts by the cartographer. In order to minimise the personal factor, the actual figures are published with the charts, so that it is open to any one interested to draw a new chart if he so wishes.

The isotherms on the map are drawn only at distances of 10° F., and ocean temperatures are shown by colouring.

The chart so drawn represents the conditions at a given

period, the period adopted for the chief chart being 7 a.m. on the day of publication. It is important to note the distinction between such a chart and the maps giving mean results with which we have hitherto been concerned. A weather chart is a *synchronous* chart, and represents the distribution of the meteorological elements *at a given period.*

With this general account of weather charts, let us now turn to a consideration of a few typical examples. We shall find that the examination of these enables us to realise generally how weather forecasting is possible. The student should supplement the description by a careful study of the "Daily Weather Report" over a considerable period.

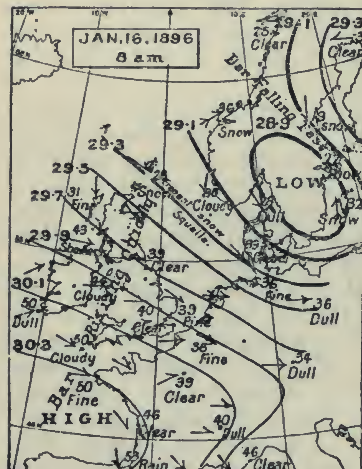


Fig. 87. Weather map showing a Cyclone or area of low pressure.

WEATHER UNDER CYCLONIC CONDITIONS.—Fig. 87 shows a reproduction of a weather chart during a period when cyclonic conditions prevailed. The general features of a cyclonic area have been already considered, and we have now to discuss the weather which prevails during its passage. Before doing this we must recall the fact that a cyclone is a moving area of low pressure, the direction of movement over the British Islands being most commonly toward the north-east. The rate of movement is very variable; it may obviously be measured by the comparison of two consecutive weather charts, for this comparison enables us to determine the distance through which the centre of the cyclone has travelled in the time represented by the interval between the two maps. We can thus distinguish between fast-moving depressions and slow-moving ones. Again, the intensity of a cyclone is measured by the maximum steepness of the gradient in it. A gradient represented by a change of a tenth of an inch, or more, over a distance of 85 miles, measured on a radial line from the centre of the depression,

is steep, and such a cyclone would be accompanied by strong winds or a gale. This quality of intensity is important, for from the intensity it can be judged whether the passing of the cyclone will or will not be accompanied by strong winds. It should be noted, however, that if a cyclone is in process of filling up then its intensity diminishes. Thus the fact that the passage of a cyclone has given rise to gales during its passage over a certain area is not in itself a proof that similar gales will arise in regions which it reaches later—it may by this time have so far filled up as to give rise to moderate breezes only.

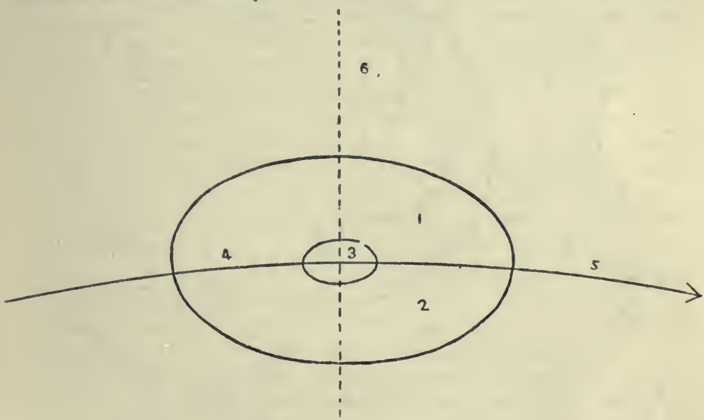


Fig. 88. Parts of a Cyclone. (After Shaw).
(1) left front; (2) right front; (3) centre; (4) rear; (5) path; (6) line of trough. The two ellipses indicate closed isobars.

According as they fill up rapidly or slowly, cyclones have lives of varying lengths, from a few hours to many days. A well-defined cyclone may affect the weather for four or five days, thus giving ample time for forecasts to be published. The approach and passage of such a cyclone is accompanied by a well-marked series of weather changes, many of which were clearly recognised, even in common speech, before their connection with barometric variations was understood.

To understand their distribution we must first consider some points in regard to the nomenclature of the parts of a cyclone (Fig. 88). The line formed by joining all the

places where the lowest pressure of a cyclone is successively recorded is called its *path* (5); it is sometimes straight, but more often curved. A line drawn at right-angles to the path through the centre is the *line of the trough* (6). The part of the depression in advance of the trough line is the front (1 and 2), that behind it is the rear (4). These points are indicated in the diagram Fig. 89. The weather changes which herald and accompany the passage of a cyclone involve

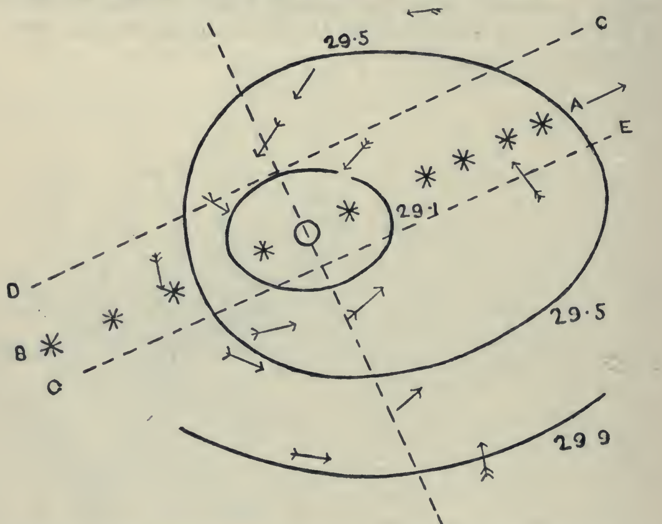


Fig. 89. Wind and weather during a cyclone. (From Shaw, after Abercromby.)

AB the path of the cyclone, the dotted line at right angles being the line of trough. CD a line drawn through a station north of the centre, and EG one drawn through another to the south of it. By following these lines across the diagram the changes of wind at the two stations can be traced. The figures indicate heights of the barometer in inches, the arrows fly with the wind and their feathering indicates the force of the wind.

temperature, pressure, humidity and wind. Let us take the first three apart from the fourth. As the cyclone approaches the air becomes close and muggy, this physiological effect being independent of the actual temperature, for the oppressive character is as marked in winter as in summer, though the actual temperature differs widely in the two cases. The

sky becomes overcast and cirro-stratus clouds appear, while the barometer drops steadily, at first slowly and then more rapidly. As the cyclone approaches the moisture of the atmosphere becomes more and more apparent, and rain begins, becoming more and more marked with its proximity; if the centre pass near the observer there is often a very heavy downpour—the clearing shower, after which the temperature rises and air becomes cooler, drier, and more bracing as the cyclone passes away.

We have next to consider the winds, and in doing this what has been already said as to the winds of a cyclonic area, together with the diagram Fig. 89, may help to make the matter clear. The winds, it will be remembered, sweep into the area of low pressure in a counter-clockwise direction, and by Buys Ballot's law the area of low pressure is always on the left hand of an observer in whose back the wind is blowing. Suppose an observer standing at E in Fig. 89 with his left hand directed towards the centre of the cyclone, the wind will be in his back and have a direction between south and east (about south-south-east). But the centre of the cyclone is approaching him, so that he must swing round to his own right to keep his left hand constantly towards the lowest pressure. Obviously then, as the wind always blows in his back it must *veer* in a clockwise direction, *i. e.* in the case indicated from south-south-east to north-west. But suppose another observer is standing at C. By a parity of reasoning we may see that in his case the wind will shift or *back* in a counter-clockwise direction from south-east through north to north-west. These two types of shift are characteristic for the two cases when the centre of the cyclone passes (1) to the north and (2) to the south of the observer.

Now it is obvious from what has just been said that when we know that a cyclone is approaching along a given path, then, if no unforeseen change of path occurs, we can foretell the probable weather along the line of the path some time before it occurs. A good many other points have to be considered, however. The distribution of pressure round the centre of a cyclone is not symmetrical, the gradients on one side being steeper than elsewhere. Where the steepest gradients occur we have the strongest winds. In large cyclones the steepest gradients usually occur at some distance from the centre, and it is here that the worst weather

is experienced. In small cyclones the heaviest rainfall usually lies round the centre, though it is not equally distributed. At the centre there is always calm, and as a general rule in the British Islands the steepest gradients and stormiest winds lie to the south of the centre. The result is that with the approach of a cyclone marked differences in weather will develop in the various districts of the region concerned; thus it is necessary to recognise in Great Britain a number of separate *forecast districts*, and to modify the forecast accordingly.

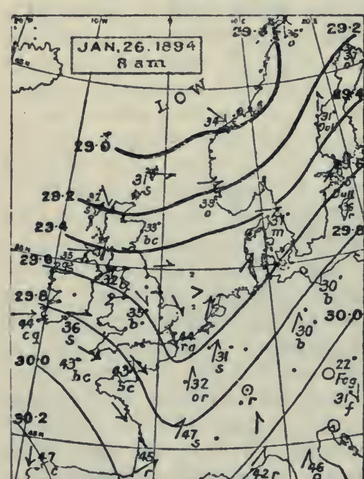


Fig. 90. A V-shaped depression or line squall.

This account of a typical cyclone suggests how it is that weather forecasting can be done, for short periods in advance, with some approach to accuracy. We must next proceed to emphasise the ways in which difficulty arises. Some of these we have already named, as the uncertainty in regard to the probable path, the possibility of the filling up of the cyclone, and so forth. These, and especially the latter, may lead to the "missing" of a foretold gale. More serious is the occurrence of an unforetold squall. This happens not infrequently from the development of what are known as secondary depressions. These induce changes of wind differing from those normal to a cyclonic condition, and often give rise to minor gales, with heavy rainfall. All stages in secondary depressions occur from mere distortions of the isobars through V-shaped depressions to perfectly formed secondary cyclones within the zone of the larger one. The approach of a V-shaped depression gives rise to the same weather conditions as an advancing cyclone, but it is characteristic that the squall or heavy rain or snow shower to which it gives rise has a limited extension in space, and within the area involved the weather is apt to change sud-

denly, clearing with great rapidity after the line of minimum pressure is past.

High-Pressure Conditions.—Having thus considered the chief features of cyclones, we should logically go on to consider anticyclones as the opposing condition. Let us, however, refer for a moment to the condition, already described, where the isobars over our area appear to be almost parallel. When a large area is considered, it is found that these apparently parallel isobars are really forming part of a great cyclonic or anticyclonic system on a very large scale. Now the interest of this observation is just this, that till recently the charts on which forecasts were based for the most part covered only small areas, and therefore, when well-defined cyclones were not present, gave a less satisfactory picture of the pressure conditions than a chart of a larger area would have done, and thus sometimes gave rise to some erroneous conclusions. A form of pressure distribution which may not be easy to recognise over a small area is one which is called a *wedge* (Fig. 92), and consists in an extension of an anticyclone between two cyclones, the extension usually pointing northwards. This condition corresponds with that already noted on p. 262, when our area lies within an extension of one of the surrounding high-pressure areas. Such a distribution of pressure is generally associated with fine weather, and seems always to indicate the presence of ascending currents of air. In such circumstances, therefore, the sky is clear, the air is dry, the winds gentle. In summer we then have our hottest and finest weather; in winter there may be much frost, accompanied by sunshine during the day, but with very cold nights, owing to the great radiation.

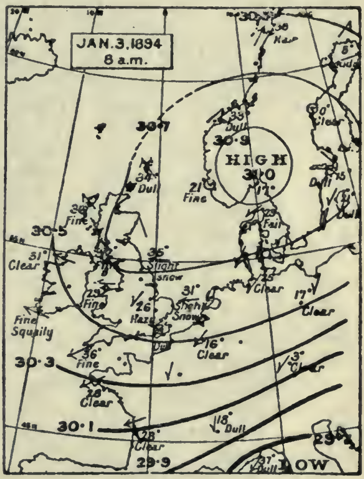


Fig. 91. An anticyclone. Note the temperatures here and in Fig. 87.

As the conditions during the presence of a wedge of high pressure are distinctly anticyclonic, it has been customary to say generally that anticyclonic weather over our area is always warm and dry in summer and cold and dry in winter. Recent work, however, seems to show that extensive well-marked anticyclones do not necessarily bring this type of weather, and are not necessarily associated with ascending currents, and thus with dry air. In the centre at least of such an anticyclone almost all types of weather may occur, except violent changes, and fog with some rain and overcast skies are frequent phenomena. Such large anticyclones are "for the most part inert and comparatively isolated masses of air, taking little part in the circulation which goes on round them." In short, it seems as if we must distinguish between those high-pressure areas which lie between cyclones and travel with them, and the larger stationary type, hitherto included under the same name. The subject is one of considerable theoretical interest, though its present significance for the elementary student is not, perhaps, very great; still, even for him the apparent distinction between the wedge of high pressure and the large stationary anticyclone is, perhaps, worth making.

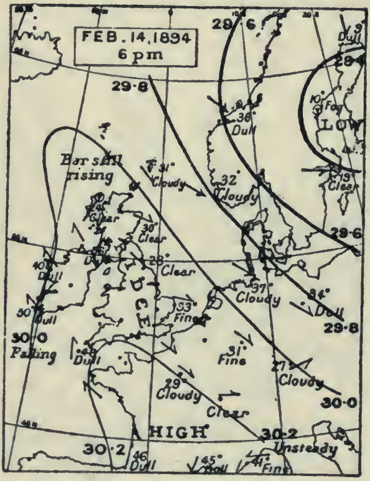


Fig 92. A Wedge or Ridge of High Pressure.

One other type of pressure distribution may be noted in a word. Where two high-pressure systems and two low-pressure ones are all present in an area, the two anticyclonic areas may be connected by a saddle-shaped area called a col. Here, despite the high barometer, the weather is often uncertain, thunderstorms occurring in summer.

The above should enable the student to study weather maps with profit, and perceive the scientific basis of weather

forecasting. The essential points may be very briefly summed up as follows. Changes in our weather are associated with the approach and passage of cyclones which come to us from the west, and tend to pass away towards the north-east. The first hint of an impending change, therefore, is to be looked for in pressure records on the west coast of Ireland, especially at Valentia. A drop of the barometer there may be regarded as an indication of the approach of a depression, and the rapidity of the fall may be taken as an indication of its intensity. The probable path is indicated by the barometers to the east of this station. If the size, intensity and path of a cyclone are known, the probable weather along its course can be gauged with fair accuracy, and differs notably in the front and rear, and also in the right and left front.

The student should make a careful study of the small weather charts forming Figs. 87, 90, 91 and 92, noting especially the temperature conditions in relation to the direction of the wind, and the pressure distribution. The cold which often accompanies a high barometer in winter in our area and on the neighbouring coasts is due to the prevalence then of an east or north-east wind, blowing from the snow-covered plains of northern Europe (*cf.* Fig. 91). On the other hand, the westerly winds of a cyclone are usually mild in winter (*cf.* the relatively high temperatures off the east coast of England in Fig. 87, with strong north-westerly winds).

It may be well to add here a note in regard to an erroneous impression sometimes produced by study of the highly abstract weather charts. When we speak of the movements of a cyclone, it is to be remembered that it is only a pressure variation which is propagated—the air has no movement of translation, any more than the water in ocean waves (*cf.* p. 286), and the student must avoid the idea of a mass of air moving bodily along the "path" of the cyclone.

REFERENCES TO SECTION V

The books on Physical Geography named at the end of Section II give longer or shorter accounts of climate and weather, but the following special books may be consulted: For meteorology two good books are Davis' *Elementary Meteorology* (1894) and Angot, *Traité Élémentaire de Météorologie* (Paris, 1899), while Bartholomew's large *Atlas of Meteorology* (1899), edited by Buchan, Herbertson and Bartholomew, is invaluable. Two small and inexpensive books may also be mentioned, Fowler and Mariott, *Our Weather* (1912), and Dickson, *Climate and Weather* (Home University Library, 1911), the latter being exceedingly suggestive, and well up to date. For climatology the great book of reference is Hann, *Handbuch der Klimatologie* (Stuttgart, third edition in course of publication). The general part of this has been translated by Ward, as *Handbook of Climatology* (1903), but the special part, only available in German, is valuable for the large number of statistics, otherwise not easily obtainable. The *Daily Weather Report* is essential, and may be obtained direct from the Meteorological Office, South Kensington, London, S.W., or from the railway bookstalls in London. In Simmons and Richardson, *An Introduction to Practical Geography* (1907), a number of useful practical exercises will be found. Finally, mention may be made of Shaw's *Weather Forecasting* (1911), a somewhat difficult book, giving full details of the principles upon which rational forecasting is based.

For the human and biological effects of climate, reference should be made to Ward, *Climate Considered especially in Relation to Man* (1908); for plants, to Schimper, *Plant Geography*, translated by Fisher (Oxford: Clarendon Press, 1903); for plants and animals to *Pflanzen u. Tierverbreitung*, by Kirchhoff (Leipzig, 1899), and for animals only, to the author's *Animal Geography* (Oxford, 1912), a much smaller book than the two last-named.

SECTION VI—THE OCEANS AND SEAS

CHAPTER XVIII

THE GENERAL CHARACTERS OF OCEANS AND SEAS

Distinctions between Oceans and Seas.—Relief of the Ocean Floor.—Distribution of Temperature in the Sea.—Composition of Sea Water.—Salinity of Sea Water.—Oceanic Deposits.

Distinctions between Oceans and Seas.—In the first chapter we gave a general account of the North Sea and of the Atlantic Ocean, and indicated the notable contrasts between the two. Thus, we distinguished between oceans and seas, noting that in the former occur the greatest depths, and that deep water covers a greater area than in the seas; the Continental Platform also has an insignificant development compared with the total area, and islands are few and not extensive; the bounding continents are, further, widely separated from one another, and the oceans intercommunicate freely. In the case of seas, on the other hand, the area covered by great depths of water is limited, and may, as in the described case of the North Sea, be completely absent. It will be remembered that that sea lies wholly on the Continental Platform, and this is a not uncommon condition. Seas, further, are bounded by a single continent and its islands or peninsulas; it is characteristic that islands are abundant, and that communication with the great oceans is more or less incomplete. Sometimes this communication takes place through a strait; at other times a submarine ridge separates the sea from the open ocean, and hinders free intercommunication of the waters. The result is that while the oceans have many common features, in regard to temperature, salinity, circulation, and so forth, seas tend to show special characters. Of this the Mediterranean, with its high salinity, is a good example.

Seas, again, can be sub-divided into the Marginal seas

(German, *Randseen*), with a wide communication with the ocean, such as the North Sea, the Sea of China, the Gulf of Mexico, and so forth, and Continental or Mediterranean Seas, such as the Red Sea and the Mediterranean, which run far into continental areas, and communicate with the ocean only by a narrow channel. The disappearance of the communication may convert such continental seas into closed seas, like the Caspian and the Dead Sea, but such bodies of water are scarcely distinguishable from salt lakes.

It is usual to enumerate five oceans, the Atlantic, Pacific, Indian, Arctic and Antarctic, but Nansen holds that the Arctic should really be regarded as a marginal sea, and not as an ocean proper. Further, neither the Arctic nor the Antarctic Oceans are adequately known.

The remaining three oceans intercommunicate freely towards the south, but are more or less enclosed towards the north, a fact which greatly influences the distribution of temperature within them. We have already (p. 18) indicated some of the chief features of the Atlantic Ocean. As a map will show, it widens towards the south and narrows to the north, where it is separated from the Arctic Ocean by the Wyville Thomson Ridge, which stretches from the north of Scotland through Iceland to Greenland, and cuts off the North Atlantic from the Arctic Ocean. Further, as already explained, the Dolphin Ridge extends from Iceland to the latitude of the Cape, being curiously bent in the tropics in a fashion which corresponds to the bend observable here in the shores alike of Africa and South America. This curved ridge divides the ocean into four compartments, two in the north and two in the south.

The Pacific, which opens more widely to the south, and is more nearly closed to the north, has no great ridge, but is remarkable for the number of its islands, most of which, however, are volcanic or of coral formation. Very remarkable is the way in which the great depths hug the coastlines, in close proximity to the great mountain chains. The greatest known depths (greatest 31,614 feet near Ladrone Islands) are in the Pacific, and its average depth is greater than that of the Atlantic (two and three-quarter miles as against two and a half miles).

The Indian Ocean, which is completely closed to the north, is proportionately even more widely open to the south than the Pacific. Islands are numerous, and it is noticeable

that the ocean is limited in its extension to a warm region. This limitation greatly affects its currents, and is the ultimate cause of the monsoon winds of Asia.

Some of the characters of the various types of seas will be noted in connection with their currents.

The Relief of the Ocean Floor.—Before leaving the great oceans we may note that the relief of their floors may be represented by contour lines, exactly as in the case of the relief of the land, though it is usual to put a negative sign before the figures of depths, to indicate that they represent depths below sea-level.

We have already noticed incidentally some of the chief forms of relief which occur on the ocean floor, but it is well to state that an elaborate international terminology has been proposed for the different forms. The most important of these are, first, the *shelf*, which has been already defined (p. 19); *depressions*, which are hollows enclosed on all sides by elevations of the sea bed, and are divided into basins, troughs, trenches, and so forth, according to their shape. Of the elevations we may note the *rise*, which is comparatively low and has gradual slopes; the *ridge*, which is long and narrow; the *plateau*, in which length and breadth are about equal.

Distribution of Temperature in the Sea.—The surface of the seas and of the oceans, no less than that of the land, is heated by the rays of the sun, and over the water, as over the land, the heating effect is greater near the equator than towards the poles. But the surface temperatures of the ocean, like the air temperature over the lands, do not show in the general case close correspondence to the latitude. In other words, isothermal lines showing the surface temperatures do not necessarily run parallel to lines of latitude (see Figs. 68, 69, 70). But the extent of the deviation between the two sets of lines is not constant. In the higher southern latitudes there is a remarkably close correspondence between the annual isotherms and the parallels of latitudes, except in the South Atlantic and southern parts of the Indian Ocean, between long. 40° W. and 60° E. Here a belt of cold water extends far north, and is due to a specially strong streaming out of polar water in this region. This at once suggests the cause of the differences between the isotherms and the parallels of latitude. The oceans, as we shall see later, are characterised by their great development of

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currents, and it is these currents which produce the anomalous distribution of temperature. The same conclusion can be arrived at negatively, by noting the uniformly high temperature of the surface in such a sea as the Red Sea (Fig. 100), which from its position stands apart from the oceanic circulation in general, and has a surface temperature notably higher than that of the open ocean in similar latitudes.

The next point of interest is the variation in temperature at different depths. Except where the surface water is at or near freezing-point, there is a steady diminution of temperature with depth, and at the same time a diminution in the diurnal and seasonal range. As a general rule the temperature is constant at depths of below about 150 feet. The actual fall of temperature, as shown in the accompanying table, is at first rapid and then slow—

Mean Temperatures of the Sea at Various Depths.

Depth.	Temperature.
600 feet.	60·7° F.
1,200 ,,	50·0° F.
3,000 ,,	40·1° F.
6,000 ,,	36·5° F.
13,200 ,,	35·2° F.

That the sun's heat does penetrate, though with great slowness, to vast depths is suggested by the fact that deep water in high latitudes is noticeably colder than deep water in low ones. This cold polar water shows a tendency to creep along the bottom towards warmer regions, and it is here that the presence or absence of ridges between cold and warm seas is important. The Atlantic, for example, is open to the Antarctic Ocean, and its deeper waters are chilled by the slow northward creep of the cold bottom water of the polar sea. But this southern opening is less wide than in the case of the Pacific Ocean, and the bottom waters of the latter are in consequence colder than those of the Atlantic. On the other hand, the Wyville Thomson ridge, though it excludes the cold *bottom* waters of the Arctic Ocean, does not prevent the cold surface water of the latter from reaching the Atlantic, which is, therefore, somewhat colder *at the surface* than the better protected northern Pacific.

COMPOSITION OF SEA WATER.—Sea water is distinguished

from fresh water by its salt and bitter taste, its slightly alkaline reaction, its lowered freezing-point and its greater weight. The fact that it is heavier is shown by the way in which fresh water discharged by rivers lies on the top of the sea water. If a weighed quantity of sea water be evaporated to dryness, it is found that solids are left behind which form about 3½ per cent. of the total. In other words, 100 pounds of sea water will yield about 3½ pounds of solids. Among these solids common salt (sodium chloride) predominates, forming over three-quarters of the whole. Dittmar's analyses (Challenger Reports) yielded the following results in regard to the more important mineral constituents—

Common salt, 77·8 per cent.
Magnesium chloride, 10·9 per cent.
Magnesium sulphate, 4·7 per cent.
Calcium sulphate, 3·6 per cent.
Potassium sulphate, 2·5 per cent.
Calcium carbonate, ·3 per cent.
Magnesium bromide, ·2 per cent.

In addition, a vast number of other elements are present, but in mere traces.

Many of these salts are doubtless brought into the sea by rivers, though the sea also perhaps to a small extent dissolves mineral matter directly from the rocks. But it is remarkable that the proportions in which the salts exist in sea water are quite different from those in which they exist in fresh water. In the latter carbonates predominate, and chlorides are insignificant; whereas, as noted above, in sea water the carbonates (carbonate of lime) are insignificant, and chloride of sodium is excessively abundant. The very small amount of carbonate of lime in the sea, despite the large quantity carried into it by rivers, is easily understood when we realise the enormous deposits which are being laid down in the sea, as the result of the activity of plants and animals. In the great ocean depths Globigerina ooze consists largely of carbonate of lime, and covers vast areas; in warm seas coral reefs occur in great abundance (*cf.* p. 99); elsewhere masses of shell breccias and limestones are being laid down, and so forth. The abundance of salt in the sea is more difficult to understand, and has given rise to many discussions. Sodium is common in rocks in various

combinations, but not as a chloride. Some authorities believe that as a result of the disintegration of rocks minute quantities of sodium chloride form, and the slow accumulation of such minute quantities in the sea has led to its present saltness. Others believe that the salt was formed in the very early stages of the earth's history, and was immediately dissolved as water formed, so that the sea was salt from its first beginning. The supporters of this view point to the fact that common salt is often produced during volcanic eruptions as an indication that the salt of the sea originated when the earth was still excessively hot, and is not derived from the rocks of the land.

In addition to solids sea water contains various gases. The chief of these are nitrogen, oxygen, and carbonic acid gas, and the amount varies with the temperature, as well as with other conditions, *e. g.* depth. As compared with air, sea water contains proportionately more oxygen and less nitrogen, and more carbonic acid gas. The carbonic acid is produced by the breathing of animals, and also by submarine volcanoes. Oxygen is absorbed from the air at the surface, and is also obtained from the activity of plants, which are, however, limited to the surface layers of water. The amount of oxygen, therefore, decreases with depth, for it only reaches the lower layers of water by slow diffusion.

Salinity of Sea Water.—Though we have given above the usual percentage of salts in sea water, it is noticeable that the actual amount varies considerably. Variations in salinity give rise to variations in density, and these in their turn give rise to slow movements, for the denser water tends to sink, and the lighter to rise. Among the factors which influence salinity are the following: (1) Rapid evaporation increases the salinity, owing to the withdrawal of water vapour; therefore, other things being equal, the sea in hot, dry regions will be salter than in moist or cool regions. (2) Heavy rain dilutes the surface layers, and so diminishes the salinity; therefore the damp equatorial regions are generally characterised by a low salinity. (3) Rivers bring in large masses of light, non-saline water; therefore near their entrance the salinity is low. One may add to these statements a note on the effect of melting snow and ice, both of which tend to lower salinity. The net result is that, theoretically, we should have near the equator a zone of low salinity; in the tropics, owing to the drying trade winds, a

zone of high salinity; in the region of the prevailing westerlies, with their high precipitation and moderate temperature, a zone of low salinity, which should diminish with the lowered precipitation towards the north, save where melting ice introduces changes. The actual conditions only correspond to this scheme in a general way, because, just as in the case of temperature, the marine currents intervene and introduce modifications. Just as in the case of temperature, so in that of salinity we find that continental seas agree more closely with theoretical conditions than do the oceans.

OCEANIC DEPOSITS.—We have already noted (p. 19) the contrast between the land-derived deposits which are found over the floor of the shallow seas, and round the margin of the oceans, and the muds and oozes which form over the bottom of the great ocean depths; but a few details must be added to what has been already said in regard to the latter. The following is Krümmel's classification of the deposits of the ocean (see Figs. 93 and 94)—

I. Land-derived deposits.
    (1) Littoral, *i. e.* those on or near the shore.
    (2) On the Continental Shelf.

II. Hemipelagic deposits.
    (1) Blue and Red muds.
    (2) Green muds and Greensands.
    (3) Calcareous sand and mud.

III. Eupelagic (deep-sea) deposits.
    (1) Epilophic (*i. e.* occurring over ridges and rises).
        (*a*) Calcareous oozes $\begin{cases} \alpha \text{ Globigerina ooze.} \\ \beta \text{ Pteropod ooze.} \end{cases}$
        (*b*) Siliceous oozes, *e.g.* Diatom ooze.
    (2) Abyssal deposits.
        (*a*) Red clay.
        (*b*) Radiolarian ooze.

Nothing need be added to what has been already said in regard to I., but the others demand further notice. Under the heading of II., Hemipelagic deposits, are included those which are intermediate in character between the purely pelagic accumulations and the land-derived ones, in that they contain elements brought from the land, in addition to the remains of pelagic organisms. If the Continental Shelf is narrow, land-derived materials may be carried beyond its margin and reach water even of over 13,000 feet in depth. Hemipelagic deposits also occur in the deeper parts of marginal

and continental seas. Where they occur near the margins of great oceans, their seaward limit is naturally quite vague, the land-derived elements gradually diminishing in quantity.

Of these Hemipelagic deposits the Red and Blue muds closely resemble one another, the colour differences being chiefly due to the compounds of iron present. *Blue mud* contains much decaying organic matter, and owes its colour to finely divided iron sulphide; it gives off sulphuretted hydrogen, and is, therefore, evil-smelling. Calcium carbonate is present in greater or less amounts, an excess converting the deposit into calcareous mud. A large amount of very finely divided rock constituents are present, especially quartz, mica, grains of hornblende, and so forth; but silicate of alumina largely predominates, forming about half the total. In addition to the lime-containing organisms whose presence accounts for the carbonate of lime, silica-secreting plants or animals are also present.

Such mud covers a considerable area in the Pacific Ocean, especially between the Galapagos Islands and Acapulco; also in the Arabian Sea and the Bay of Bengal, and in the Mozambique Channel. It has also been found by recent Antarctic expeditions in the far south. In the vicinity of volcanic vents fragmentary material of volcanic origin may so predominate as to convert the mud into a volcanic sand; while where it forms off coasts whose rivers flow over deposits of laterite (*cf.* p. 53) it acquires a red colour from the iron oxide of that deposit, and becomes *Red mud*. This is especially the case off the Atlantic coast of tropical South America. Loess deposits have a similar effect, so that Red mud appears in the eastern part of the China Sea.

Green mud and *Greensand* are characterised by the abundance of glauconite, which is a greenish mineral consisting of silicates of iron, potash and alumina, of doubtful origin. When grains of glauconite predominate the deposit is called Greensand, while Green mud has fewer such grains, and contains a considerable amount of fine clay, which, in addition to alumina, includes fine mineral particles of various kinds. Remains of foraminifera are frequent, the shells being often filled up with glauconite; organic matter is also abundant. Such muds and sands are especially characteristic of steep coasts off sub-tropical countries where large rivers are few; for example, they occur off the eastern

United States south of Cape Hatteras, off the coast of Portugal and of California, etc.

Calcareous muds and *coral sands* occur especially in the deep basins of tropical and sub-tropical continental seas, and off coral islands, especially in the Pacific Ocean. In them carbonate of lime predominates, foraminifera being very abundant; mineral elements are insignificant, those of volcanic origin being most in evidence. Such muds are, therefore, very near the Globigerina ooze of the open ocean, except that the contained foraminifera are in part ground-living forms, and there is also a much greater variety of organisms, such as Pteropods, sponge spicules, Radiolarians, etc. Such deposits occur especially in the Gulf of Mexico. On the other hand, the calcareous muds which accumulate in the Mediterranean contain a much larger amount of land-derived material.

Passing now to (III.) the Eupelagic sediments, we find that the so-called epilophic forms avoid the deepest basins, and follow the line of the rises and ridges, so that their presence over certain areas of the map tells us something of the depth conditions there. The most widely distributed of these is *Globigerina ooze;* a chalky deposit which consists predominantly of the shells of pelagic foraminifera. Mingled with these are small amounts of shells, etc., of ground-living organisms, and traces of land-derived material, the last very small in amount. As Fig. 93 shows, Globigerina ooze is especially abundant in the Atlantic and Indian Oceans. It reaches its maximum development in depths of 1,500–2,500 fathoms.

Over relatively limited areas the shells of the molluscs called Pteropods come to predominate in the chalky ooze, and then the name of *Pteropod ooze* is given. Below some 1,500 fathoms these delicate shells are dissolved by the sea water, and the distribution of this ooze is therefore limited to depths of from 500–1,500 fathoms. In these depths it occurs off certain tropical islands, *e. g.* round the Azores, on the outer side of the Antilles, to the west of the Canary Islands, and so forth. In cold waters foraminifera tend to be replaced by the algæ called diatoms, which form a shell of silica. We thus find that in the far south a ring of Diatom ooze encircles the globe, replacing here the calcareous oozes of lower latitudes. The same type of ooze reappears in the North Pacific (Fig. 93).

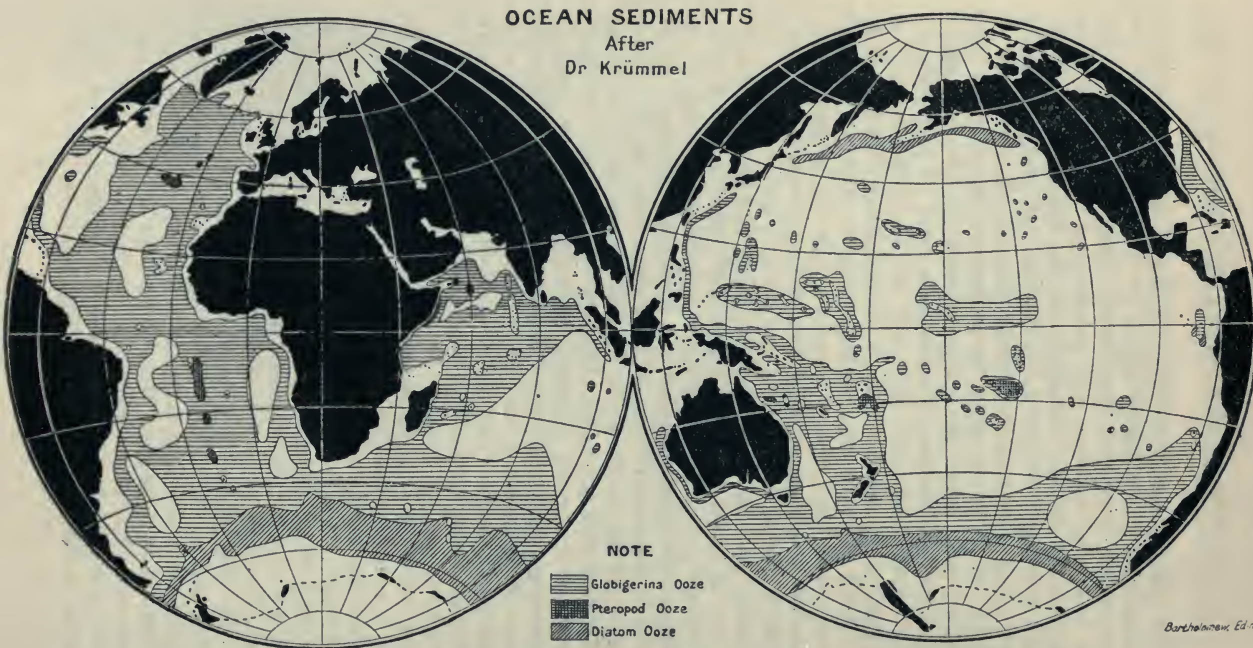

Fig. 93. Distribution of Globigerina, Pteropod and Diatom Oozes.

All the deepest parts of the ocean bed, and therefore especially the floor of the deep Pacific, are covered by *Red clay*. Lime-containing organisms which fall through these deep waters have their hard parts completely dissolvĕd away before they reach the bottom, and therefore no Pteropods nor foraminifera occur in these deposits; but in certain regions siliceous shells are present, and give rise to a variety of Red clay which, from their presence, is called *Radiolarian ooze*, Radiolaria being small and simple animals which possess siliceous shells.

Red clay never occurs in depths of less than 2,200 fathoms. Its uniformly red colour is due to iron oxide, and it consists almost exclusively of minute particles of silicate of alumina, thus forming a true clay. In addition, minute particles of volcanic material (especially pumice, which being light, is easily carried by winds), nodules of manganese, meteoric dust, with occasional teeth of sharks and ear-bones of whales, are found. The nature of the teeth, which sometimes belong to extinct species of shark, speaks to very slow accumulation, while the ear-bones owe their presence to their excessive density, the rest of the skeleton having presumably been completely dissolved. Red clay, as Fig. 94 shows, covers a very large area in the Pacific Ocean, while it has a more limited extension in the Indian Ocean, and in the Atlantic occurs in six isolated patches, none of which is large. A point of some interest is that if we divide the globe into a land and a water hemisphere, Globigerina ooze predominates in the first and Red clay in the second.

Radiolarian ooze is distinguished from Red clay by the presence of many siliceous organic remains, especially the shells of Radiolaria, the frustules of diatoms and the needles of sponges; except for this addition, its general characters are those of the Red clay. Its distribution is much more limited. Absent from the Atlantic, in the Indian Ocean it occupies merely a small area round Christmas and the Cocos Islands, while in the Pacific it covers considerable areas, especially between lat. 5° and 15° N. (Fig. 94).

A point of great interest with regard to these deposits is that, while the land-derived and hemipelagic types are represented in indurated form by existing rocks, it has been denied that any rock exists which can be regarded as an indurated deep-sea deposit. Huxley regarded Globigerina ooze as the modern representative of the chalk, but detailed study has

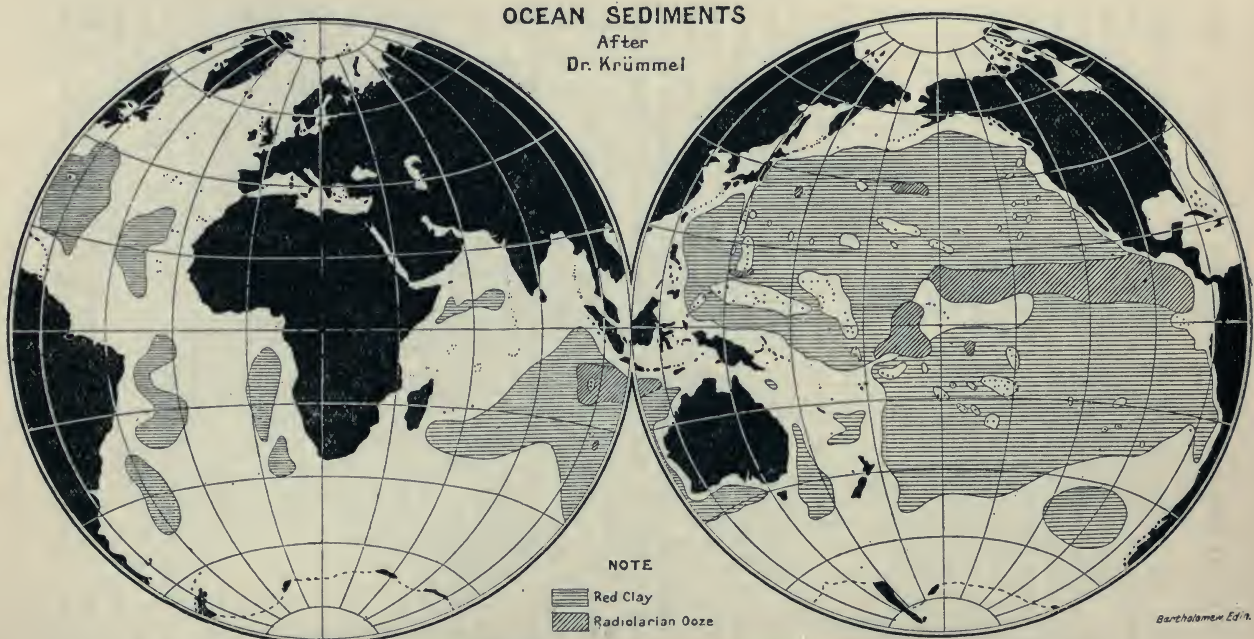

Fig. 94. Distribution of Red Clay and Radiolarian Ooze.

led to the recognition of many minor differences which some geologists regard as a proof that the chalk was formed in water much nearer land than that in which the ooze is now forming. No rock has been yet described which can be regarded as having originated from Red clay, and, generally, the paucity of rocks which can be plausibly regarded as having originated from deep-sea sediments is a remarkable feature. Some authorities regard this as a proof that the great ocean depths have been permanent—that is, have never formed parts of a continent. Others, who do not accept this view of the permanence of the ocean basins, point to the fact that relatively few rocks, except in Europe, have been subjected to detailed microscopic examination. It is possible, therefore, that rocks derived from deep-sea deposits may yet be discovered within continents, or on their borders; but there is still another possible explanation, and this is that the great ocean depths which now exist are a recent phenomenon, associated with the development of the huge Tertiary mountain chains; the oceans of earlier epochs may have been more extensive but not so deep.

According to Suess, an old continent, Gondwanaland, once stretched across the Indian Ocean over areas now covered by Red clay and Globigerina ooze, and the same continent is supposed to have stretched from Africa to South America over areas where Red clay and Globigerina ooze are also forming, while at the time when Gondwanaland existed parts of what is now South America, with Central America, were believed to have been covered by ocean. This condition is thought to have lasted at least throughout Primary time, if not later, and it is inconsistent with the theory of the permanence of ocean basins, at least in its extreme forms.

CHAPTER XIX

THE MOVEMENTS OF SEA WATER

The Types of Movement.—Waves.—Tides and their Causes.—Currents.—Causes of Surface Currents.—The Currents of the Great Oceans.—The Currents of the Seas.

The Types of Movement.—The waters of the seas and oceans show two different types of movements. In the one, exemplified in waves and tides, no actual displacement of the particles occurs, for each tends to describe a curve, returning to its original position as the wave passes on. In other words, a particular state of motion is handed on from one part of the water to another, energy and not matter being transmitted. In the other type, that of ocean currents, the particles of the water undergo actual displacement.

Waves.—These need not detain us long. They originate in the general case by the action of the wind on the surface, and the effect of oil in calming a storm-tossed sea is due to the fact that the smooth film of oil prevents the wind from obtaining any purchase on the water. Waves may arise from other causes, *e. g.* from volcanic outbursts and earthquakes, and they also originate, as we shall see, in connection with tides. The top of a wave is the *crest*, the depression between two adjacent waves the *trough*, the *vertical* distance between trough and crest is the *height* of the wave, and the distance between two successive crests is the *length*. There have been great disputes as to the height to which waves reach. That they attain heights of 20–30 feet seems certain; that they rise sometimes to 50 feet is asserted, but on more doubtful evidence. More interesting is the question of the depth at which wave motion continues to make itself felt. Some 150 feet is probably the extreme limit of this.

We have already stated that waves usually originate from the action of the wind. At a given place in the ocean the wind which has produced the waves may continue to act. In this case the movement tends to become irregular;

secondary waves develop on the flanks of the original ones. Further, as the crest is more exposed to the wind action than the lower part of the wave, it tends to move faster, and so "breaks" in a shower of spray. In this case part of the water has a definite movement of translation, though this is limited in extent. On the other hand, waves may extend far beyond the zone where they arose originally, like the ripples which spread from the spot where a stone was cast into a still pool. Such waves form a ground-swell, and may occur when there is no trace of wind. The usual "roughness" of open seas is due to the fact that waves are continually reaching any given area from all directions.

As waves approach the shore their lower parts have their velocity checked by friction against the ground, while the upper part continues to move with the original velocity. The result is that the wave once again "breaks," forming the characteristic breakers of the shore. The higher the waves and the flatter the shore, the better developed are the shore breakers. Shores where tides are strong tend to have a well developed littoral platform (see p. 97), and over this the waves break strongly, so that landing or embarking is rendered difficult—hence the necessity for sheltered havens if maritime traffic is to be carried on. Africa suffers severely from the absence of bays and harbours on her coast-line, which is almost everywhere particularly exposed to shore breakers. The waves dash up the sloping beach and then sweep back again, producing the dangerous backwash or undertow.

Tides and their Causes.—In the open ocean the level of the water rises and falls twice in every twenty-four hours, but this is a movement which it is difficult to perceive or measure. On the other hand, on shores, especially those of inlets and estuaries, tidal phenomena are very obvious and easily measured. For example, on most British shores we find that twice a day the water advances or flows up the sloping shore to a well-defined limit, called high-tide mark, while twice a day it retreats or ebbs to a limit called the low-tide mark. Round high-tide mark débris of various kinds, especially torn-off seaweed and wreckage, tends to accumulate, so that the line is more or less permanently marked on the shore; similarly, on most shores the growth of particular kinds of seaweeds marks the low-tide mark. Thus, the weed called Laminaria, or oarweed, grows just

beyond low-tide mark, only a few inches of its long stems being exposed at the lowest ebb.

But despite the fact that the upward and downward limits of the movement are thus definitely marked, the dimensions of the tides are far from being uniform. On some days the tide rises very high (spring tide), these days being also days when it retreats far, so that there is a very low ebb. On other days the waters advance a relatively short distance and retreat but a short distance (neap tides). A very little observation will show that these phenomena recur at regular intervals. Twice a month a high spring tide occurs, the height diminishing after each spring to a minimum neap tide, and then increasing again till a new spring occurs in the following fortnight. Further, high tide does not occur at the same time every day. On every successive day the time of high tide is about 48–50 minutes later than on the preceding. The spring tides at a given place thus occur at approximately the same hour throughout the year. Tides are of such importance to navigation that they are carefully studied by all civilised communities, the results being published in nautical almanacks and elsewhere. The accompanying table, giving the tides for a fortnight at Leith, shows the main facts as regards the movements of the water there. It will be noted that at Leith the maximum height of the tide in the fortnight indicated is nearly twenty-five feet, the difference between spring and neap tide being 4 feet 2 inches.

TIDE TABLE—HIGH WATER AT LEITH

Days.		Time. Morning.	Time. Afternoon.	Depth on Dock Sill.
Saturday	*JAN. 6**	*3 33*	*3 58*	*24′ 10″*
Sunday	Jan. 7	4 24	4 50	24′ 7″
Monday	Jan. 8	5 15	5 40	24′ 1″
Tuesday	Jan. 9	6 5	6 30	23′ 9″
Wednesday	Jan. 10	6 55	7 21	22′ 11″
Thursday	Jan. 11	7 47	8 14	22′ 1″
Friday	Jan. 12	8 43	9 14	21′ 4″
Saturday	Jan. 13	9 46	10 19	20′ 10″
Sunday	*JAN. 14*†	*10 53*	*11 25*	*20′ 8″*
Monday	Jan. 15	11 56	— —	20′ 9″
Tuesday	Jan. 16	0 26	0 54	21′ 1″
Wednesday	Jan. 17	1 19	1 41	21′ 9″
Thursday	Jan. 18	2 2	2 21	22′ 4″
Friday	Jan. 19	2 39	2 56	22′ 9″

* Spring Tide. † Neap Tide.

THE MOON.

Full Moon	Jan. 4	1h. 30m. p.m.
Last Quarter	Jan. 11	7h. 43m. a.m.
New Moon	Jan. 19	11h. 10m. a.m.
First Quarter	Jan. 27	8h. 51m. a.m.

Tides scour out estuaries, and so keep them open. In consequence, ports tend to spring up at the upward limit of tides, which is also the point where the river can first be bridged with ease—of this Newcastle, London, Bordeaux, etc., are examples; but it is noticeable that, with the modern increase in size of ships, there is a tendency for this original port to be replaced by outports further down the estuary—all the towns named afford examples of this.

Tides influence navigation in another way. Sometimes they are so violent as to constitute a "race," the waters flowing with great rapidity first in one direction and then in the other. A good example is the tidal current which pours through the Pentland Firth, off the north of Scotland. Such races tend to occur where a sudden constriction is found on the course of an enclosed piece of water; an example of this is Hell Gate near New York. In all such cases there is a period of indeterminate current, called by sailors slack-water, or the slack of the tide, before the complete reversal of the stream sets in.

When the tidal wave enters the broad, shallow estuary of a large river, carrying much water, the interference of the current of fresh water and of the shallow bottom with the tidal water often produce the phenomenon called a bore, or eagre, which is a steep and wall-like wave, whose height increases as the estuary narrows inland. Such a tidal wave occurs in England in the Severn and Trent estuaries, also in such rivers as the Seine, Amazon and Ganges. Bores are especially large at times of spring tide, and are greatly influenced by winds.

The above description of the actual movements of waters in connection with tides seems at first sight inconsistent with the statement made on p. 286, that tides, like waves, consist in a transmission of energy and not of material particles. To solve the apparent contradiction it is necessary to consider the cause of tides. The occurrence of a monthly period, and the fact that on successive days there is a difference of about fifty minutes between the times of high tides suggests a relation with that heavenly body whose

revolution occupies a month, and which shows a period of about fifty minutes between two successive meridian passages. In fact, tides owe their origin to the attraction exerted by the moon on the land and water of the earth; but the actual effects are enormously modified by the distribution of land and water, etc.

Let us suppose, in the first instance, that we have a globe completely enveloped in water; in that case, as the diagram shows (Fig. 95), the waters on the nearer side would be attracted by the moon, and would tend to rise in a tidal swelling at A. A similar swelling would occur at B, because the moon's attraction is here greater on the land than on the water, so that the earth seems to be pulled away from the water. At C and D there would then be low tide, which would correspond to the troughs of the huge tidal waves whose crests are at A and B. The rise and fall of the tide in this simple theoretical case would be about two feet, and if no other agent intervened there would be no variation in the height of the tides. The variation is due to the intervention of the sun, which, being much further away, exercises less influence than the moon, but still produces a small solar tide. But before beginning to discuss this point let us consider the propagation of the tidal wave. If the earth and moon were stationary, then in our theoretical case it would always be high tide at A and B. The effect of the motion of the earth is to cause the tidal wave to move round the earth in a direction opposite to that of the rotation of the earth, *i. e.* from east to west. The inertia of the water produces a slight lag, so that the crest of the tidal wave is never exactly beneath the moon, but slightly behind it (*cf.* the figures in the Tide Table with those showing the phases of the moon during the same period). We shall see that the varying depths of the oceans and seas and the varying forms of the shores produce such marked irregularities that the actual conditions show little apparent relation to this theoretical one.

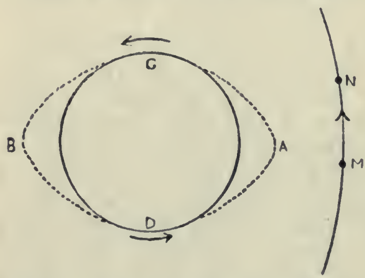

Fig. 95. Diagram to illustrate the cause of tides. (For explanation see text.)

The next point to be considered is the cause of the constant change in the time of high tide at any given place. As the earth rotates every twenty-four hours, it might be supposed that at the end of that period the tidal wave should return to the same spot. But while the earth has revolved, the moon has moved in its own orbit from M to N, therefore the earth has to turn a little further to overtake the moon.

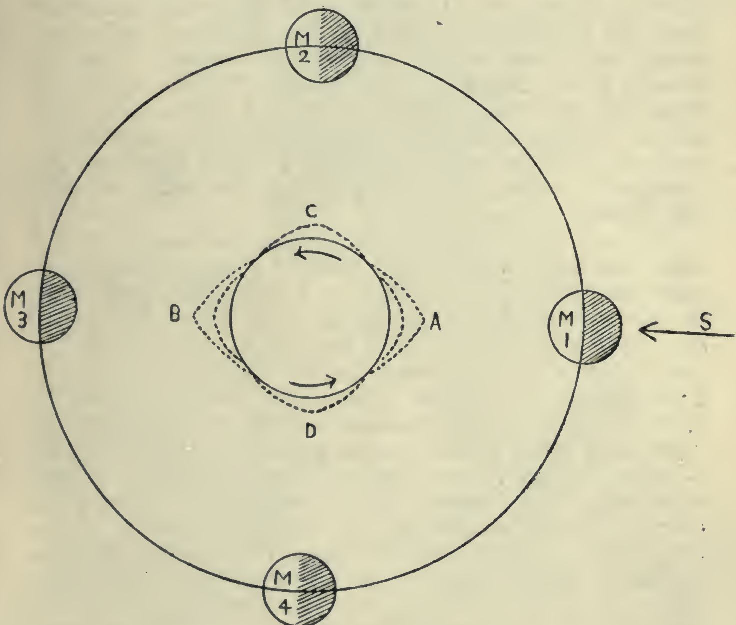

Fig. 96. Diagram to show the cause of spring and neap tides. (For explanation see text.)

The distance which she has to turn through is equivalent to the distance between two meridian passages of the moon, about fifty-one minutes.

The diagram (Fig. 96) shows the causation of the phenomenon of spring and neap tides. When the moon is in the position M_1, she is said to be new, and the sun reinforces her action. Both moon and sun exert an attractive influence which tends to draw the water towards them, and so give rise to a high tide at A. At the same time they attract the

land more strongly than the more distant water at B, with the result that the water seems to be attracted in the direction AB, so that high tide occurs also at B. At the end of a week the moon has moved to the position M_2. Now, her attractive force acts at right angles to that of the sun, with the result that the high tide produced at C is due to the difference between the two forces, and is a small or neap tide. With the movement of the moon to M_3 at the end of another week, her force is again added to that of the sun, and a new spring tide occurs at this period of full moon. With the passage of the moon into the position M_4, the conditions seen when she was at M_2 are repeated, and a new neap occurs. Spring tides, for the reason already mentioned, do not quite coincide with new and full moon; there are also a number of other causes of minor variations which we need not consider here.

We have next to consider the contrast between the actual conditions and those of our theoretical globe enveloped in a continuous envelope of water. As the tidal wave approaches the continents it passes into the shallow water which covers the Continental Shelf. Here its velocity is checked, the length of the wave is diminished and the height increased. Two consequences result. First, the actual rise may be many times greater than in the open ocean, and, second, there is an actual transference of particles of water, in place of a mere transmission of energy; this is comparable, though on a much larger scale, to that which takes place when ordinary wind-raised waves approach the shore. At the same time, the tidal wave undergoes great modifications in direction. For example, off the western coast of Europe the wave appears to come from the west instead of from the east, and in the Atlantic Ocean it travels from south to north. The tides are far from being known in detail over the whole globe, but, on the other hand, they have been carefully studied off the coasts of the more civilised countries. Such observations make it possible to draw what are called co-tidal lines, which are lines connecting points where the tide is high at the same time by Greenwich time. Such lines enable us to follow the course of the tidal wave, and a map on which they are indicated is the best way of studying the subject (see Fig. 97).

We may note here a few points in regard to the tides off the British Islands. The tidal wave strikes the coast of

Fig. 97. Co-tidal lines in the British Isles.

Ireland, and then travels north and south, one part sweeping past the coast of Scotland and through the Pentland Firth, and another penetrating the English Channel and sending a branch up St. George's Channel. The first gives off a branch which enters the North Channel, and meets the wave which has entered the Irish Sea from the south through St. George's Channel. As a result of these movements, the tide is high simultaneously at Liverpool, Dover, and places a little to the east of the Pentland Firth. The northern tide splits into two off the north of Scotland, sending one branch along the coast of Norway into the Skager Rak, and another down the east coast of Britain. The two tidal waves—those from the north and south—meet and neutralise one another at a point in the North Sea midway between Holland and England. The meeting of the two currents results in the precipitation of those immense banks of sand which form the Dogger Bank (*cf.* p. 15). Wherever islands interfere with the movements of the tidal wave, a similar splitting of the current occurs; to this is due the phenomenon of four tides in the day at Southampton, where a tidal wave advances through Spithead two hours after one has arrived through the Solent. In the marginal and continental seas, tides are either insignificant or not developed.

Currents.—As contrasted with the oscillatory movements of waves and tides, currents involve a true circulation of the waters of the ocean, and profoundly modify these as regards both temperature and salinity. We have to distinguish, in the first place, two types, the surface and the bottom currents. The latter escape direct observation, and are yet but little known; they are determined by differences of salinity and temperature, and tend to equalise the differences produced at the surface by the superficial currents and the varying atmospheric conditions. The surface currents, on the other hand, can be studied directly by various methods, and are indeed in some instances very obvious. Initiated, as it would seem, chiefly by the wind, they profoundly modify the distribution of temperature and salinity over the surface, and greatly affect the climates of the continents. They involve the movement of the superficial waters down to a depth which does not exceed 1,600 feet, and they create those anomalies of temperature and density which the bottom currents strive to correct. Their rate of movement is often great, and in this respect, also, they are contrasted with the slow bottom currents.

CAUSE OF SURFACE CURRENTS.—The causation of currents is a subject which has been greatly discussed, and is still not fully decided. It seems that we can distinguish between primary and secondary causes—that is, between those from whose action the currents originate, and those which determine the particular direction of a given current. Among the primary causes or components of the current are (1) causes within the water, such as differences in density, themselves caused, as we have seen, by differences in salinity and temperature, the result of variations in the sun's heat, in the amounts of evaporation and rainfall and melting of ice; (2) external causes, such as variations in atmospheric pressure and wind. Among the secondary components are (1) friction, which takes various forms in connection with the other causes; (2) the rotation of the earth, which affects the direction of movement (Ferrel's law, *cf.* p. 91); (3) the form of the ocean basins, which exercises a very marked influence on the direction of the currents. Different geographers are by no means agreed as to the relative stress which is to be laid upon these different elements, but it seems clear that the constant trade winds have much to do with starting

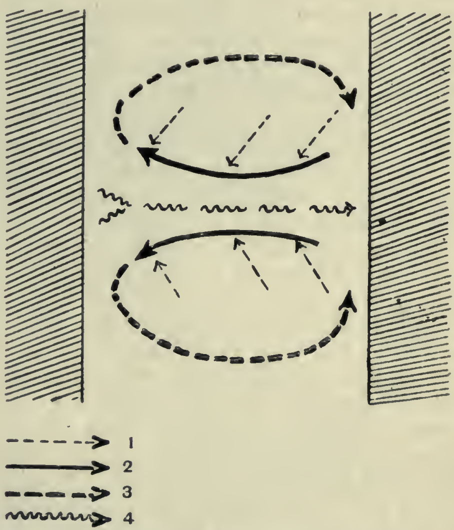

Fig. 98. Diagram to indicate the origin of currents. (After de Martonne.)

The shaded regions at the side indicate continental areas: (1) the direction of the trade winds at either side of the equator, giving rise to (2) the equatorial currents; (3) the currents which complete the circuit in both hemispheres; (4) the return of compensating equatorial current.

that great system of swirls which is so marked a feature of the oceans.

THE CURRENTS OF THE GREAT OCEANS.—Before proceeding to details in regard to these, we may note that the diagram (Fig. 98) shows what would be, theoretically, the course of the currents in an ocean bounded by uniform continents. The trade winds, acting upon the surface water, tend to produce currents which, owing to the effect of the earth's rotation, express themselves as movements with a generally westerly direction. These north and south equatorial currents impinge upon the continental shelf of the western continent, and tend to rebound to the north in the one hemisphere, and to the south in the other; but as they travel north or south they are subjected to an increasing force due to the earth's rotation, and therefore swing round in huge edies. Between the two equatorial currents a return current exists with a west to east direction.

Turning now to the Atlantic, we find that the form of the continents influences notably the theoretical condition (Fig. 99). The south equatorial current impinges on the projecting coast-line of Brazil, and splits into two, sending a northern branch to reinforce the northern equatorial current, in addition to that which travels along the south coast of Brazil. Let us take the northern branch first. Combining with the north equatorial current, it forms the very powerful Caribbean Current, which is split by the Antilles into two parts. The northern portion, or Antillean Current, is the true origin of the Gulf Stream, but the southern portion, which enters the Gulf of Mexico, is there reinforced by the current which streams out of that hot saline sea, and emerges as the current of Florida, which gives additional force to the Gulf Stream. Strictly speaking, that name is a misnomer, for the "Gulf Stream" is in reality a derivative of the equatorial current.

The *Gulf Stream*, the powerful current which rises in the fashion just described off the coast of Florida, has an ill-defined right edge, for here its waters are being continually swept into the equatorial swirl. Its left bank is rendered precise by the cold Labrador Current, which sweeps down the coast of the States, and originates from polar currents of which one comes down the eastern side of Greenland. The two streams run side by side in opposite directions, their contact producing a sudden lowering of temperature, the Cold Wall. Towards the south the *Labrador Current* under-

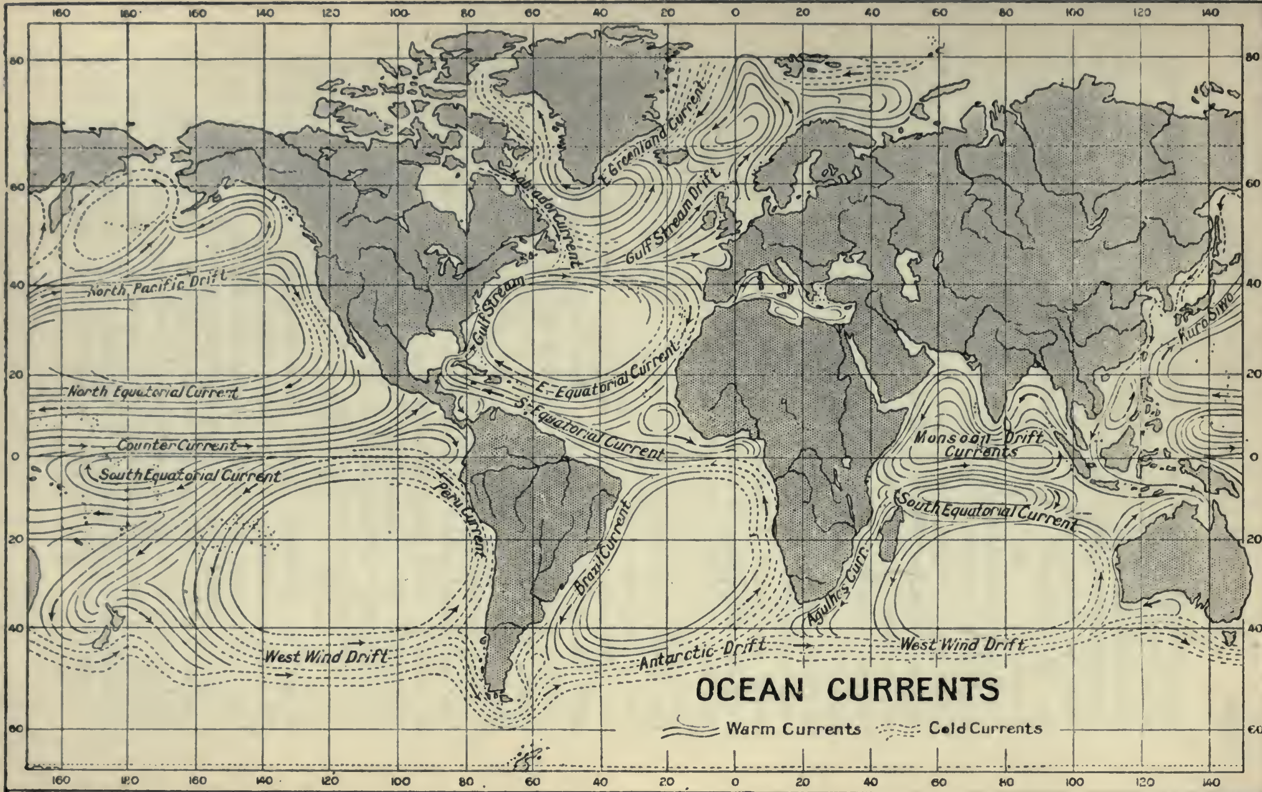

Fig. 99. The Chief Currents of the Great Oceans.

lies the Gulf Stream, so that soundings give a very abrupt change of temperature below a certain point. Further to the north the cold polar water comes to the surface, and at Cape Hatteras there are curious streaks of warm and cold water, as if the currents interlaced. Opposite Newfoundland the Gulf Stream, to some extent, breaks up. Part of its waters sweep southward, and, owing to the rapidity of the movement, cold bottom water finds its way to the surface, so that the relatively cold *Canary Current* originates. The other part forms the *North Atlantic drift*, or European current, which splits into three parts, the Greenland branch, which flows past the west coast of Greenland, the Irminger branch, which passes northward between Iceland and the east coast of Greenland, and the Norwegian branch, which is drawn northwards past the coasts of the British Islands and Norway.

In the South Atlantic the current system is somewhat simpler, retaining the theoretical shape of a great swirl. The warm *Brazil Current* corresponds to the Gulf Stream in the north, and the cold *Benguela Current* to the Canary Current. The return, or *Guinea Current*, is not well marked in the Atlantic.

A phenomenon of some interest in connection with the Atlantic currents is the so-called Sargasso Sea, a mass of floating weed, with an associated great wealth of marine animals, which occupies the slack-water in the centre of the North Atlantic swirls, lying to the east of Florida. In maps the area covered by this mass of weed is indicated very precisely, and text-books often give exact figures, *e. g.* those of Maury, who describes the sea as extending from long. 19° to 66° W., the eastern portion extending from lat. 17°–30° N., and the western from lat. 22°–28° N. From recent observations, however, it would appear that the limits are very vague, the compact mass of weed indicated in maps being non-existent. The weed seems to be largely torn off from the shores of the Bahamas, and floats for a time in the still waters, before sinking to the bottom.

Another phenomenon dependent upon the Atlantic currents is the presence, at certain seasons, of icebergs and field-ice in the North Atlantic in relatively low latitudes. The ice is brought down by the Labrador Current especially from the coast of western Greenland, and constitutes a great danger to navigation off Newfoundland in spring. So cold

are the waters of the ocean here that icebergs may occur in May, in long. 40–45° W., so far south as lat. 39° N., that is south of New York and Madrid. The resultant danger to navigation is greatly increased by Great Circle sailing (see p. 175), which brings ships far to the north while crossing the North Atlantic, and was strikingly exemplified by the sinking of the *Titanic*.

Turning now to the Pacific Ocean, we find that the regular form of the basin permits the simple condition indicated in Fig. 98 to persist to a large extent. As in the Atlantic, the southern equatorial current is the most important, and its eastward-flowing branch is so rapid as to result in the up-welling of cold bottom water, as in the Atlantic, forming here the cold *Peru Current*, which greatly affects the climate of the Galapagos Islands. The return equatorial current is more powerful than in the Atlantic, and as it impinges upon the Pacific coast of Central America forms a series of minor swirls which give the region its characteristically hot and rainy climate (*cf*. Fig. 79). With this the climate of the Galapagos Islands, exposed to the cold Peru Current, is markedly contrasted. Another peculiar feature of the South Pacific circulation is the way in which the warm limb of the southern equatorial current sweeps into the kind of basin formed between the eastern coast of Australia and New Zealand; it is this current which gives New Zealand its warm and moist climate. Again, the cold water of the South Pacific doubles Cape Horn, and, being caught in the South Atlantic circulation, helps to chill the Benguela Current.

In the North Pacific the Japanese Current, called the *Kuro Sivo*, is the equivalent of the Gulf Stream, but, as it is not displaced by so powerful a polar stream as that current is, it cannot penetrate so far north; whence the lower limit of cereals on the west coast of America as compared with the west coast of Europe.

Both in the Pacific and Atlantic Oceans there is some seasonal variation in the currents, but it is in the Indian Ocean that this is most marked. Here the northern circuit shows a complete reversal in summer and winter, owing to the action of the monsoons. In summer, a north equatorial current travels from east to west, and, turning northwards, skirts the coast of Africa, and then travels from the Arabian Sea into the Bay of Bengal; at this season the northern current thus takes the normal course. But in winter the

flow is from the Bay of Bengal into the Arabian Sea, and then from the east coast of Africa eastwards to the Malay region, so that there is thus a complete reversal of the summer currents.

THE CURRENTS OF THE SEAS.—The currents of the marginal and continental seas, though less well-defined than those of the oceans, illustrate some interesting points. The first point to emphasise is the effect of ridges or ocean rises on the temperature of such seas. This is well illustrated by the diagram (Fig. 100), which shows the junction between

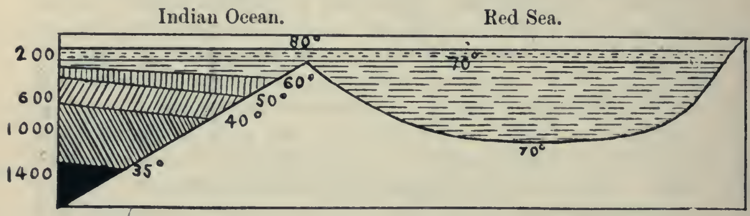

Fig. 100. Temperature conditions in the Red Sea and Indian Ocean. (Modified from Salisbury.) To the right is the relatively shallow Red Sea, separated by a distinct sill from the much deeper ocean. The sill prevents the cold deeper layers of the ocean from reaching the Red Sea, whose waters have throughout the temperature of the surface waters of the ocean. The figures within the diagram represent temperatures in degrees Fahrenheit, those on its margin depths in fathoms. The shading indicates the temperature of the different layers of water.

the Red Sea and the Indian Ocean. It will be noticed that, while the surface waters of the two communicate freely over the ridge, it prevents the cold, deep waters of the Indian Ocean from entering. In consequence, the Red Sea waters throughout their depth have the same temperature as the surface waters of the Indian Ocean. Quite similar conditions are present on either side of the Straits of Gibraltar, where they are even more marked; the waters of the Mediterranean having throughout their depth a temperature which is possessed by the surface waters only of the Atlantic. Generally, marginal seas have throughout their depth the temperature which occurs at the level of the ridge which separates them from the adjacent ocean. But in the case of both the seas named the density is high, despite the high temperature. Both occur in warm regions (the Red Sea in a hot one), where the rainfall is slight and the evaporation

great, and consequently there is much evaporation and a high salinity is reached. In parts of the Mediterranean the salinity exceeds 3·9 per cent., that of the adjacent part of the Atlantic being about 3·6 per cent. In the north of the Red Sea the density exceeds 4 per cent., while in the Indian Ocean it is 3·7 per cent. In both cases, therefore, the dense waters draw in the less saline waters of the open ocean, with the result that there is an in-current from the ocean to the sea in both cases. This current is a surface current, and beneath it there is, despite the obstructing ridge, an outflowing of the warm sea water to mingle with the colder ocean water—that is, a return current in lower layers of water.

Let us contrast this condition with that of the Arctic Ocean, which consists of a deep basin separated from the Atlantic by rises. Here, owing to the melting of snow and ice, the surface layer of water has a very low salinity and low temperature; this layer extends down to about forty-five feet. Below it, extending downwards to about 800 feet, comes a layer of cold water whose salinity, though higher than at the surface, is still low owing to the fresh water poured into the ocean by the Siberian rivers. Still deeper, and extending to about 3,300 feet, comes a layer of warm saline water, originating from the Gulf Stream. The deeper waters do not enter into the general circulation. The surface waters, cold and fresh, stream westwards across the Polar Sea, and in part leave it along the eastern coast of Greenland. At the same time the waters of the Gulf Stream, or North Atlantic drift, enter the Polar Sea, but these waters, denser than the polar waters, plunge beneath them. In essence, therefore, we have here the out-streaming of a cold light layer of water at the surface, and an in-streaming of a heavier, because salter, but yet warmer layer beneath. The condition is thus the reverse of that which takes place in warm seas like the Red and Mediterranean, where the in-current is of fresher water than that of the sea, and the out-current is of salter water. The one condition is as characteristic of warm, saline seas as the latter is of fresher, cool or cold seas. Thus the Baltic, whose waters are cold and nearly fresh, sends a surface current into the North Sea and draws in the salter water of the Atlantic. The details of the currents here are, however, very complicated, and are of great importance in connection with the distribution of fish.

All such currents are superficial and the deeper waters, especially of continental seas, tend to stagnate.

Thus there seems to be almost complete stagnation in the deep waters of the Black Sea, and in consequence life is absent in its depths. Its waters are of relatively low salinity, owing to the large rivers which drain into it, and in consequence a certain amount of its light waters are drawn through the sea of Marmora into the Mediterranean, these being doubtless compensated for by a return current as usual; but these movements do not affect its depths, which measure some 10,000 feet, and contain throughout water of low salinity.

REFERENCES TO SECTION VI

There is a great lack in the English language of a good *modern* book on Oceanography. Most of the general works on Physical Geography already mentioned gave more or less full accounts of the ocean, but the authoritative work is Krümmel, *Handbuch der Ozeanographie* (Stuttgart, 1907 and 1911. Second edition in two volumes). The student will also consult the general volume of the *Challenger Report*.

SECTION VII—HUMAN GEOGRAPHY

CHAPTER XX

THE EFFECTS OF THE PHYSICAL CONDITIONS ON HUMAN LIFE

Races of Man.—Factors which Influence Density of Population: (1) Coal and Facilities for Transport; (2) Water-power; (3) Natural Fertility.—Sites of Towns, as illustrated in the Rhone Valley.

In the preceding chapters we have noted incidentally, more especially in the chapter on climate, how the physical conditions influence human life and human activities. The subject which treats this in detail is the department of geography which is often distinguished as Human Geography, though the ultimate purpose of all geography is to consider the natural conditions in their relation to man, and physical geography can only be regarded as forming part of the subject when this end is kept in view. The subject of geography is, however, so wide in its scope that distinctions which have little foundation in logic must meantime be kept up, and we thus distinguish between physical geography in the narrow sense, which is mere description, and that larger science which discusses the conditions in the light of their significance for human life. The previous chapters have been predominantly, if not quite exclusively, descriptive, and in this the concluding chapter we must at least indicate the ways in which the geographer in the broad sense utilises such facts, and builds up from them a reasoned science. The small space at our disposal here only permits this to be done in the merest outline, but this outline will to some extent be filled in during the student's study of political and commercial geography.

Races of Man.—Two outstanding facts emerge from the most superficial study of man's distribution over the surface: (1) His extraordinarily wide distribution as compared with other organic beings, and (2) the remarkable variations

in density of population exhibited by the different parts of the globe.

In regard to the former point it is noticeable that few animals or plants afford any analogy to the width of human distribution. Some of his nearest allies, such as the orang and gorilla, have a very limited range in the tropical forests. and perhaps the nearest analogy to his wide extension among the higher forms of life is to be found in the cats. With few exceptions (*e. g.* Australia, New Zealand, Madagascar, and many small islands), almost every part of the world contains true cat-like animals. But when we come to detail we find that the particular species of cat present is not always the same. The lion has a wide distribution in the Old World, but there is no true lion in the New World, though large cats occur there presenting superficial resemblances to the lion in colour and other ways. Does man present similar conditions? We cannot discuss the question here in detail, but may content ourselves with stating that the vast majority of naturalists and anthropologists are agreed that all living human races fall into one species only. But this species runs into a number of separate races, in regard to which a few words must be said.

The classification of the human races is a matter of great difficulty. We shall adopt here one of the simplest, based primarily upon the characters of the hair.

I. In one great division of men the hair is FRIZZLY (WOOLLY), that is each hair is closely rolled upon itself, and is flattened in cross-section. Races with hair of this type have long or dolichocephalic skulls; that is if the length of the skull from front to back be taken as 100 and the breadth between the ears be stated as a fraction of this length, it will be found that the breadth is under 80 (75–78). If, as happens in some other races, the ratio of breadth to length equals or exceeds the ratio of 80 to 100, then the skull is described as broad or brachycephalic.

The frizzly-haired peoples may be divided into two groups: (1) the Oceanic, and (2) the Western. Among the former are included the Papuans, Melanesians and the extinct Tasmanians. Among the latter are the various negro tribes of Africa, including the pigmy bushmen. In the oceanic groups the skin is not so dark as among the negroes, nor are the lips so thick nor the nose so flat. Cultivation among these peoples is only practised to a small extent or

not at all (Tasmanians), but among the Papuans and Melanesians boat-building is often highly developed. The negroes of Africa generally practise agriculture, but, except where taught by higher races, they do not plough, they manure little or not at all, and they have no idea of the rotation of crops. Whether from these causes alone, or because of the relative infertility of the soil throughout negro Africa, their land loses with great rapidity its power of producing crops, and is rarely kept under permanent cultivation. Many of the crops now grown were introduced by other races, and there is reason to believe that before the introduction of these famine must have been frequent in negro Africa.

II. The next group consists of races with Straight Hair, round in cross-section, brownish or yellowish skin, and usually broad heads. People with these characters occur in America, where they form the aboriginal races (Red Indians); the Mongolians of Asia belong to the same division, as do the people of the Philippines, the Malays, the Eskimos of the north, etc. The colour of the skin is variable, but is generally yellow or brownish. Some tribes of American Indians cultivated to a limited extent. Among the Mongolians of Asia some are pure pastoral peoples, others, like the Chinese and Japanese, are extraordinarily skilful cultivators. The highly specialised Eskimos do not cultivate at all.

III. The third great group is that of the Wavy-haired peoples, who have hair intermediate in character between the two other groups; their head form and skin colour are also highly variable. They are represented first by the Australians, practising no cultivation, incapable of building any but the most rudimentary type of shelter, but with a very elaborate tribal system, whose object was apparently to minimise the dangers of the intermarriage of related persons. To the same division belong the brown-skinned Polynesians, most of the peoples of India, the Hamites, ancient Egyptians, the Semites, Arabs, and other stocks of northern Africa and the adjacent areas, and practically the whole of the population of Europe. From the very early days peoples of this division have been distinguished by their skill as cultivators, but it is remarkable that isolated stocks, such as the Australians and certain tribes in India, do not cultivate at all, or practically not at all.

Space does not permit us here to consider these three groups in detail, but we may note briefly that in Europe the wavy-haired group occurs in three well-marked divisions. To the south we have the rather short, moderately long-skulled, dark-haired Mediterranean stock, which in the west extends as far north as Ireland and Wales. Along the band of elevated land which stretches through the centre, reaching the seaboard in Belgium, and forming important elements of the community in Germany, Hungary, Russia, etc., we have the so-called Alpine stock, with broad heads, colouring intermediate between fair and dark, and moderate stature. To the north, predominating in Scandinavia, North Germany, most parts of Great Britain, etc., is the Nordic or Teutonic race, tall in stature, generally fair in colouring, and moderately long-headed. These varied stocks only seem to blend to a very limited extent.

When we examine animals in detail, we find that all show a certain harmony with their environment, due apparently to a long process of evolution. The more limited the distribution of a particular form is, the deeper, in the general case, is the stamp of that environment upon it. Can we similarly explain the peculiarities of the races of men by their particular surroundings? The question is a very difficult one, partly because of man's power of consciously modifying his habits to suit special conditions. In every part of the world he is modified by the physical conditions, but we have no means of knowing how deep these modifications go. Even so apparently simple a problem as the effects of climate on the different races and sub-races has become vastly complicated by the discovery that what were once regarded as climatic effects are largely the results of parasitic disease; a fact which makes it dangerous to lay down any general statement on the subject. The following points seem, however, worth note.

Looking at the races of the world broadly, we may notice that most blending of races, together with the greatest interchange of products and ideas, has taken place in the great Eurasian continent, and there the most successful types have evolved. In Africa, south of the great desert, the negroes have been more or less isolated till recent times, the influence of the wavy-haired groups having only filtered slowly across the deserts. Whether because of this isolation, or from other causes, the negro stock has prospered less than the other

great stocks, and especially has never risen to great skill in cultivation. At the same time the fact that a slow filtration of racial and social influences has from time immemorial reached the African negroes from the north, is perhaps one of the causes why they have proved so resistant in their recent intercourse with higher groups, while completely isolated stocks, like the Tasmanians and Australians, have gone down completely, or nearly so, as soon as the breath of the outside world reached them. It would seem then that isolation is incompatible with full human development.

We may notice also that the long chain of islands which stretches from the Malay peninsula southwards has been a highway of migration for countless ages, for here all the three great stocks meet, the most successful being those nearest the Eurasian continent, the most degraded those furthest from free communication with these stocks.

Factors which influence Density of Population: (1) *Coal and Facilities for Transport.*—Let us turn next to the question of the reasons why certain parts of the globe are densely peopled with human groups reaching a high degree of civilisation, while others are scantily peopled. At the present time those strains of the wavy-haired races which occur in Europe, or have migrated from Europe to other parts of the world, seem to have been most successful in the conflict with nature, but this is because to their ancient skill as agriculturists they have added, within recent times, an enormous superiority to all other strains in mechanical means of transport, and mechanical means of doing work generally. These powers are based upon an extensive use of the refractory metal, iron, and have developed in regions where abundant power is available. For the most part this power has been hitherto obtained from coal, and therefore the greatest recent development has taken place along a band which stretches from the west of England across the continent of Europe to Poland, and along another broad band, also rich in coal, found in the eastern United States. Both these regions are districts of dense population, this population depending primarily, not upon the fertility of the land, but upon its wealth of minerals, and the facilities offered for free intercommunication with neighbouring regions by modern methods. This fact may perhaps be best realised by a consideration of the shift of centres of wealth and population in England. The old England had its centre of

gravity in the fertile south and south-east; in the new England wealth and population accumulate round the coal-fields, regions most of which were once barren moors.

In addition to the presence of rich coal-fields, that broad, prosperous belt which runs across Europe enjoys many minor advantages. Among these are the presence of the broad Continental Shelf, covered by a shallow sea, whose borders lodge many secure seaports. In this respect Great Britain is especially fortunate, for Ireland shelters it largely from the Atlantic rollers, which beat so fiercely on the coast of Spain and Portugal, and it has thus important western seaports, in addition to the eastern ones. Again, the position on the western margin of a great continent, facing that broad ocean over which much raw material comes, is a great advantage, while the rich fishing-grounds of the shallow sea afford a source of food of great importance in supplementing the yield of the land. The westerly position also, as we have already seen, makes the climate mild and moist, especially on the seaboard, a fact which is not without its commercial significance, notably in the manufacture of cotton, which requires a moist climate. Again, lofty mountain ranges are absent, and the wide European plain offers little obstacle to transport, and makes it easy to construct roads and railways. In Germany, and to a less extent in England, the inland waterways are important, for they facilitate the transport of bulky goods.

In the United States some of these advantages again exist, but the special points here are the great wealth of minerals, and the great extent of fertile agricultural land, together with the facility of communication over the wide plains by land and by the excellent waterways.

(2) *Water-power.*—While up to the present the presence of coal and iron have been the determining factors in promoting the development of European countries within recent times, there is evidence of a beginning of a change, which may possibly lead to great modifications in the distribution of the population in the future. Owing to the recent glaciation the mountain regions in Europe and North America, as we have already seen, show a remarkable development of "hanging valleys," the side streams entering the main valley in the Alps, or reaching the sea in the case of Norway, after leaping over lofty precipices in waterfalls. This gives a remarkable development of water-power, which is just

beginning to be utilised on the large scale in the generation of electricity. In the Alps the water-power has been largely used for some time for lighting purposes, and also as a motive power in railways. It is now being increasingly used for industrial purposes, especially on the Italian side and in the French Alps, and this is also beginning to be done in Norway. Of great theoretical interest is the use of this electrical power for the manufacture of artificial nitrogenous manures from the air. This industry only requires as condition for its existence abundant water-power, atmospheric air and limestone, the latter abundant in the mountain regions which furnish the power. It is stated that already in Norway saltpetre (sodium nitrate) can be manufactured so cheaply in this way that it can be sent to South America in competition with the saltpetre of Chili, which requires merely to be picked up from the desert regions of that country. The demand for such substance is steady and continuous, as contrasted with industries, *e. g.* the shipbuilding trades, in which there are extraordinary fluctuations. This is of importance because the industrial town as we know it in Great Britain, Belgium, Germany, etc., is enormously influenced by the fact that many important industries make demands on a large floating population, which constitutes the reserve of labour, called upon in times of special stress. It seems possible that the new industries now arising in the mountain regions of Europe will not require this labour reserve, which swells the city to huge proportions and introduces manv difficult problems, and may therefore give rise to a totally different type of community. Further, while coal is excessively costly to transport over land surfaces, electrical power can be transmitted cheaply, another cause which will prevent communities employed in industries using electrical power from displaying that close aggregation over a very limited area, which is so characteristic a feature of the coal towns. As has been often remarked, a rich coal-field tends to become dotted with almost continuous towns, which house the workers employed in the raising of the coal, as well as those needed for the industries for which the coal is required. The result is that a considerable area of country may be more or less completely sterilised, and this not only means a rise in the price of food, all of which has to be brought from a distance, but means also a loss of health and efficiency on the part

of the workers, and a sharp division line between "town" and "country," which has many indirect effects.

(3) *Natural Fertility.*—We have discussed first among the densely populated regions those which owe their population to their coal and the related industries, and are for the most part fed from other regions of the world. This is obviously a late development, for it would be impossible if other regions were not growing food and raw material in excess of their own wants. Before the industrial revolution, regions of dense population were mostly regions of great natural fertility. Such regions are to this day crowded with human beings, having as many persons per square mile as the densely peopled industrial areas. For example, in the Midland valley of Scotland, with its wealth of coal and iron, there are over 512 persons per square mile; but the same figure recurs in the valley of the Nile, in the Ganges valley in India, round Shanghai in China, in the island of Java, etc. But in the latter districts the density of population is due, not to mineral wealth, nor to water-power, but to the capacity of the land to produce enormous amounts of food material. Only to a very limited extent are the people of the Midland valley of Scotland fed on home-grown products. The surrounding seas produce fish; the land feeds cattle and sheep, and produces a certain amount of cereals and other crops; but nearly all the wheat, much of the meat, much of the butter, eggs and cheese, all the sugar, and a great many other articles regarded as necessary are supplied by other lands. The regions mentioned above feed their own teeming populations, and supply a surplus of agricultural products for export. In all these regions, except in the case of the valley of the Nile, the cereal rice, enormously prolific, but demanding great care in cultivation, is a very important crop, and its high yield is one cause of the density of population.

The monsoon regions of south-eastern Asia have always been densely peopled areas. In China the richest and most densely peopled regions include the great plain which stretches from the mountains north of Peking to the Gulf of Hang-chow, also the valley of the Yang-tse, and the coastal belt which bounds the mountainous region of southern China, especially the rich tropical delta of the Si-Kiang, whose outlet is Canton. All this region is favoured by its climate (*cf.* p. 241), the fact that the heavy rainfall

coincides with the highest temperatures of the year being specially important. Much of the region is also favoured in its soil, for in the valleys of northern China we have that fertile, easily-worked soil called loess, whose properties have been already discussed (p. 54). Again, in the province of Sechuen the tributaries of the Yang-tse bring down from the mountains a rich alluvial soil, red in colour, derived from the decomposition of red grits apparently of Jurassic age. The name of Red Basin is given to the region where this red soil occurs, and here the surrounding mountains modify the climate so that it is warm in winter and hot in summer. The rainfall is somewhat deficient, but this is made up for by elaborate irrigation works, and so productive is the soil that the steepest slopes are carefully terraced so that they may be used for cultivation. Throughout China generally manuring of the land is carefully practised; it is also noticeable that the great elevation of the interior of Asia means the existence of long and rapid rivers which carry with them a great load of alluvium, and this preserves the fertility of the land by adding new elements to replace those removed with the crops.

The same thing is true of the densely-populated parts of India. The valley of the Ganges, for instance, has its fertility perpetually renewed by the waste of the Himalayas, and the abundant monsoon rainfall here is of great importance in promoting the growth of crops.

In the Nile valley the Nile has the same fertilising power, and the absolute necessity for using its silt-laden water for irrigation purposes in the rainless land of Egypt, necessarily meant from the earliest times that the fertility was retained despite assiduous cropping. Such conditions are of great importance, for *e. g.* the African negro has never learnt of himself the reason why his cropped land so rapidly ceases to yield. It seems unreasonable to regard this as a racial peculiarity when we recollect that the Australians never learnt to cultivate at all till they were taught by Europeans, and they belong to the same race as that which has cultivated the lands of the Nile valley from the remote past. But if a group finds itself in a region where the land-fertility is automatically renewed by alluvium-carrying water, its prosperity is assured, and it has that power of accumulating a reserve which seems necessary for intellectual development. Incidentally we may note that in Egypt the shape

of each peasant's holding, a narrow strip running back from the river, but always with a river frontage, shows the intimate connection between the river and Egyptian agriculture.

Large river valleys, where the climate is suitable, not only favour agriculture because their waters bring rock waste from the distant mountains, and because they themselves, fed by the snows of those mountains, make irrigation possible during the hot season when it is most wanted; they have the further advantage that the loose alluvial soil is easy to work, incomparably easier than the peaty soils of the northern moors with their layer of "pan," or the glacial clays of the northern plains, or even the laterite of many tropical districts. Where, however, they occur in regions with a permanently high rainfall, then they may be so overgrown with dense tropical vegetation that clearing is a matter of great difficulty. Thus the huge Amazon basin is very scantily peopled, it being impossible for peoples in the lower stages of civilisation to clear and maintain cleared an area where growth is so rapid as it is here. On the other hand permanent or periodic drought makes forest growth impossible, and renders it far easier for man to displace the natural herbaceous crops by his own. This must have been a factor in promoting the early settlement and prosperity of Egypt, Mesopotamia and Babylon.

Sites of Towns.—We have now noted briefly some of the conditions which render particular parts of the earth's surface densely peopled, whether with industrial peoples, clustered close about the coal-fields, or with more scattered agricultural populations. The converse problem, why other regions are scantily peopled, cannot be considered here, but we may note that in many cases climate is an important factor. We must, in conclusion, turn for a moment to that special problem of why, in densely peopled regions, those compact groups of human dwellings which we call villages and towns, should occur in certain situations. As in the few pages at our disposal we can only hope to look at a few general points, it may be convenient to follow down that great river, the Rhone, whose course we have already considered in detail, and note the causation of the types of settlement which occur on its banks, rather than to limit ourselves to statements on towns in general.

If we begin where the river leaves the mountain region for the broad valley we find, as already indicated, that villages

appear (see Fig. 22, p. 71) on the alluvial cones where the side streams enter the main valley. Here they are safe from the winter inversions of temperature (*cf.* p. 256), they minimise the risks of flooding, and they have near them sloping ground well fitted for cultivation. But if these considerations help to account for the placing of the villages at particular points in the valley, they leave untouched the larger question why villages should occur here at all. To understand this we have to note the contrasts of climate and products between the broad valley and the mountain regions which hem it in. The main valley is, especially toward the centre, swampy, constantly liable to flooding, the floods spreading stones and débris over the land. At the margins, however, the land is safer from flooding, and as it slopes up escapes the cold mists which hang in winter over the ice-cold stream. These marginal lands, therefore, are capable of cultivation, producing more and more valuable crops as we descend the valley. On these slopes the vine flourishes, so precious a crop that it is marked specially on the Swiss map; on the flatter grounds fruit-trees grow freely, as well as cereal crops, hemp, and so forth.

With these conditions those which obtain in the mountains are contrasted. As we have already seen a very steep ascent usually leads up from the main valley into the lateral ones owing to the way in which these "hang." Therefore as we ascend these lateral valleys we rapidly pass the zone of cultivation and enter the fir-woods. Here, then, is a timber-producing zone. This timber is an absolute necessity for the dwellers in the valley, for they require it both as fuel and as material for building houses and for making furniture. Where the lateral valleys are of any size we commonly find that after the first steep ascent we reach a region of slighter slope, where the valley is wider, often forming a little basin. Here the conditions found in the main valley repeat themselves, for we find a considerable village, placed on a shelf where it is above the winter chills, and surrounded by its belt of cultivated land. As we have already seen, many alpine valleys consist of a series of such basins separated by regions of steep slope, usually densely wooded. As we ascend, however, the climate begins to make cultivation impossible, and the uppermost villages are mere shanties of rude construction, with no cultivated land near. These are merely summer villages, and lead us to the

next great resource of the mountain—its pasturages. These render a large pastoral industry possible, and the way in which the pastures at successive levels become clear of snow in spring and summer involves constant migrations on the part of herds and herdsmen. Wherever the accessibility makes this possible the luxuriant grass is cut and stored as hay, but the inaccessible regions must be cropped by the cows and goats, and cheese made on the spot. The produce of these pastures is thus exported in the compact form of cheese, because the difficulties of transport make it impossible to carry away so bulky a product as hay.

The meaning, then, of the villages in the main Rhone valley in the Valais, no less than of the villages in the basins of the lateral valleys, is that these are junction regions, regions where the products of cultivated land can be exchanged for the wood, cheese, milk, butter, meat, hides, etc., of the mountain. In not a few cases in this somewhat isolated region there is little actual exchange, for the villagers are migratory in mass, now cultivating the vine in the Rhone valley, now herding their cows on the high alps, now acting as woodcutters in the forests. But in the general case we may say that where two regions yielding different products meet, there settlements tend to arise, because there is a possibility of trade.

One other factor has to be noted. Not a few of the lateral valleys afford more or less easy means of crossing the chain and so finding a way into Italy, whose products on the whole are different from those of Switzerland. The villages which lie at the points where such lateral valleys enter the main one thus become *nodes*, points where traffic routes meet, and acquire additional importance on this account. Brig, which has long been important because it lies at the point where the easy Simplon route enters the main valley, has increased considerably since the opening of the Simplon tunnel, because of the through traffic. Martigny, which commands the St. Bernard route, as well as some other less easy passes, is another example of the same thing.

Sion, a nodal town commanding routes of minor importance to the north and south, as well as the main valley, illustrates another point of some interest in connection with the origin of towns. Differential erosion in the valley here has given rise to several isolated rocks and hills, and these bear ruins of important buildings of various ages,

e. g. a Roman fort, mediæval castles, ecclesiastical buildings, etc. The town also has been besieged several times. These facts show that when a site forms the natural centre of a productive area, offers special facilities for defence, and commands the main route through which the traffic of the district passes, it tends to become a centre from which authority, military, governmental and ecclesiastical, is exercised, and as such may for a prolonged period enjoy an importance out of proportion to its real significance as a trade centre. Such towns tend as a rule to lose importance in modern times, for they rarely form important nodes on the modern highways of commerce; they then frequently take on a secondary importance as centres of education, or of art, etc. Sion is, of course, a very insignificant example of such conditions; many others might be given. We may also note that where such historical centres stand at a node which has kept its importance in modern times, they may show a curious combination of decay and vitality. York, at once an active railway centre and a decaying cathedral city, is an example. Durham, with its small manufactures based upon the adjacent coal-field, and its old-world cathedral close and castle, illustrates much the same thing, and many other examples might be given.

Leaving out all consideration of the other lake towns, let us turn now to Geneva, an admirable example of a town placed at a node. It is now a junction of several railway routes, *e. g.* to Culoz and so to Paris on the one hand, and to Lyons and Marseilles on the other, to Annecy, to Chamonix, to the towns on the north and south banks of the lake, and so on, while it is also of considerable importance as a centre of the lake traffic, and marks the point where water transport ceases, for the Rhone after leaving the lake is too swift for navigation. It has, however, the great disadvantage of having the Jura close at its back (*cf.* Figs. 3 and 21), which renders communication difficult by rail, and thus, though it stands at the end of the Swiss plateau, it is not suited, like Basle, to become an important modern commercial town. From the standpoint of present-day conditions it has also the great disadvantage of being far from coal, though it has good water-power. From its position at a node, however, with fertile land round about, it has a long tradition behind it, which makes it an educational centre, and also a centre for those manufactures which demand workmen with a

tradition of skill and patience. The mountain folk in the adjacent hills find themselves condemned to long periods of idleness so far as outdoor work is concerned, and tend, therefore, to take up skilled indoor employments, such as the making of jewellery, parts of watches and mathematical instruments, wood-carving, and so forth. Geneva drains the products into itself, and uses its water-power to complete the process of manufacture. The difficulties of communication make it necessary that trade should be carried on in articles costly in proportion to their bulk, *i. e.* demanding much skilled labour in their manufacture. Perhaps owing to their long isolation the Swiss on the whole are deficient in artistic taste, and devote themselves chiefly to articles requiring technical skill. Like many towns in Switzerland, especially those in or near the mountains, Geneva has an important "tourist industry," but it is not wholly a tourist town, like Montreux, for instance.

Leaving Geneva, let us pass to the next large town on the river, that of Lyons. This is superbly situated at the junction of the transverse Rhone with the longitudinal Saône, on that great depression which has always been one of the highways of communication between the Mediterranean region and the north. It is near coal (St. Etienne), and from its position has a long tradition of skill behind it, as well as of artistic feeling. To the south lies the favoured region of Provence, with a warm climate, while its natural outlet is the great port of Marseilles, situated to the east of the mouth of the Rhone, admirably placed for free communication with the east, where Lyons gets much of its raw material. (Note that the delta of the Rhone, due to the entrance of the river into a quiet sea, prevents the formation of a port at the mouth.) In Provence the mulberry is grown, and the small proprietors have a traditional skill in the rearing of silkworms. They supply to some extent the silk-looms of Lyons, but it receives also an enormous amount of silk from the East, as well as some from Italy. In carrying on this trade, its easy communication with Italy through the Alps, with the East and the Mediterranean seaboard by the Mediterranean, and with Paris and the north *viâ* the valley of the Saône and the Côte d'Or are of enormous importance, while the peculiar climatic conditions which obtain in Provence and on the Riviera, and enable these districts to grow crops, such as fruit (including in the

Riviera oranges and lemons), olives, early flowers, and so forth, for which there is a great demand in the less favoured countries to the north, give Lyons a large through trade.

The clustered towns further south, such as Avignon, Arles and Nîmes, if of minor significance relatively to the huge towns of the coal regions, are of great interest as showing us old-time towns whose prosperity depended upon the fertility of the surrounding district. Their magnificent old buildings, dating from many different epochs, help us to realise the value of that fertility through long ages, though it now seems of minor importance as compared with the wealth which is being dug out of the coal-fields.

Summary as these notes on the causation of the sites of towns are, they may serve to indicate the way in which physical geography affects the various problems involved.

REFERENCES TO SECTION VII

The subjects which have been touched upon in this chapter are so vast that full references would involve a large bibliography. The following are a few outstanding works: For races of men see Deniker, *The Races of Man* (1900); Haddon, *The Races of Man*, a concise summary; Ripley, *The Races of Europe* (1900), with many interesting sketch-maps. A short summary of the subject will be found in *General and Regional Geography for Students*, by Unstead and Taylor (1911), while the six volumes of Reclus, *L'Homme et la Terre* (Paris, 1905–8), should be consulted for the relation between the different races and their surroundings. The subject of trade and the rise of modern towns falls into commercial geography, on which the standard work is Chisholm's *Commercial Geography*, many editions. Anthropo-geography in a more generalised sense is discussed in such books as Ratzel, *Anthropogeographie* (first edition, 1882, Stuttgart); Semple, *Influence of Geographic Environment; on the basis of Ratzel's System of Anthropo-Geography* (1911); Brunhes, *La Geographie Humaine* (Paris, 1911). The author's *Man and His Conquest of Nature* (1912) gives summaries of some recent researches on the subject. Finally, we may note that fuller bibliographical information on this and the other sections of this book is to be obtained from *Guide to Geographical Books and Appliances* (1910).

APPENDIX

THE GEOLOGICAL FORMATIONS

GEOLOGISTS recognise the following periods in the history of the earth, which are identified by the rocks laid down during each—

PRIMARY

(1) Archæan or Pre-Cambrian, the oldest rocks of all, containing no fossil remains, and of great hardness. They occur specially in Canada, in the north-west of Scotland and Ireland, in Scandinavia, Finland, parts of Russia, etc., and form worn-down uplands, mostly infertile.

(2) Cambrian, in Great Britain specially developed in Wales, hence the name. Many fossils occur, but the rocks again mostly form relatively infertile uplands, which yield slates and such minerals as iron, silver and small quantities of gold.

(3) Ordovician. In Great Britain many of the rocks of this age are old lavas, showing that the period was one of great volcanic activity. They occur in Wales, the Lake District, and southern Scotland.

(4) Silurian, rocks largely developed in the Lake District of England, in Wales, and in the southern uplands of Scotland. The limestones of this period are of economic importance, but the regions where the rocks occur are not generally fertile.

(5) Devonian or Old Red Sandstone, beds sometimes marine and sometimes freshwater, often crumbling to form fertile soils, such as the red soil of Dunbar, famous for its potatoes, and the fertile soils of Devonshire. During this period earth movements seem to have occurred on the grand scale, producing mountain chains in northern England, Wales, Scotland, and Scandinavia; the worn-down remnants of these chains now form the uplands of Scotland, northern England, Wales, etc.

(6) Carboniferous, including rocks of enormous importance to Great Britain, for all our coal, almost all our iron deposits, the oil-shale of Scotland, and many beds of lead ore occur in rocks of this period. Other rocks of the same period of economic importance are ganister, a kind of sandstone used in lining the vessels employed in the iron industry, limestone used as a flux in the same industry, fire-clay, etc., During this period folding again occurred, producing the Armorican chain, represented now by the uplands of Devon and Cornwall, south-west Ireland, and Brittany.

(7) Permian, consisting of sandstones and limestones with marls.

SECONDARY

The second period saw the evolution of birds and mammals and the modern types of plants. During it enormous masses of chalk and limestone were built up. It includes—

(1) Triassic beds, of sandstones, marls, etc. (with deposits of rock salt), which form fertile beds over part of the English plain.

(2) Jurrasic beds, consisting of limestone, marls, clays, shales, etc., which also form fertile beds.

(3) Cretaceous, deposits consisting of chalks, sandstones, clays, etc. The chalk forms uplands which carry sheep, the softer beds form fertile tracts, notably in the Weald of Kent.

TERTIARY

This period is represented by a great many different types of rock, which, as we have seen, were folded up to form the lofty mountain chains of the world, and are now in process of being worn down again to sea-level. In England, where there was no folding during the period, the beds of this age are soft and form fertile soils in the English plain. The London clay of the Thames valley is an example. During the period (Eocene) when this deposit was laid down the climate of England was warm, and the trees which grew in the Thames valley resembled those found in tropical and sub-tropical regions, especially those which occur in the type of climate which we have called Chinese (see p. 243). As the Tertiary period went on, the climate grew steadily colder, until it passed into the next period.

PLEISTOCENE OR POST-TERTIARY

This was the great ice age or glacial period, whose deposits have been described in Chap IX. With the gradual passing away of the ice age, present conditions developed.

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THE END

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